

Chapter Four, Safety Analysis

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4.1. Introduction

The design of the Collider Accelerator Department's suite of ion injectors, accelerators, the collider and the experimental facilities is based upon the experience and successful designs employed since the initial startup of the AGS in 1960. The basic approach for the safety analysis has been to review the potential hazards for each major segment of the facility. Hazard analysis is the standard method for applying the DOE graded approach for minimizing risk. It is well suited to identifying and understanding risk because it requires consideration of both the likelihood and the potential consequences of hazards. The product of likelihood and consequence constitutes the risk. When using risk as the measure of acceptance, the allowable consequences for lower likelihood events are higher than for the higher likelihood events. In the hazard analyses presented in this chapter, the approach has been to evaluate the risk and to identify preventive and mitigating features and controls that ensure that risk is acceptably low. Because the suite of facilities follows consensus codes and standards, standard industrial hazards are adequately addressed and their risks minimized without the need for detailed hazard analyses.

4.2. Hazard Analysis Approach

Hazard analyses include hazard identification and screening, assessment of the potential consequences of unmitigated risk, identification of relevant and effective mitigation/preventive measures, and finally, assessment of mitigated risk. Hazard analysis makes it possible to understand the risk and make informed risk acceptance decisions. It is desirable to be able to show that the C-AD Facility risks are in the "extremely low" category (see Table 4.2), and an

effort to do so has been made in this section of the SAD. The hazard identification process used the C-AD Facility design and operating information; BNL site documents; facility walk-downs to identify potential hazards within the complex that could adversely affect the workers and environment; and discussions with the engineers and users of the facilities. The hazards evaluation process is a largely qualitative assessment of potential accidents or impacts in terms of hazards, initiators, likelihood estimates, preventive or mitigating features and public, environmental and worker consequence estimates. A maximum credible accident scenario for each major portion of the complex is presented later in this chapter, the consequences of which bound all those to workers, the public and the environment. The results of these analyses confirm that the potential risks from operations and maintenance are extremely low. The hazards involve those present at all high-energy ion accelerators and experiments such as radiation, chemical, biological, electrical, magnetic fields, rf fields, energy sources, pressure and vacuum, material handling and lifting, heights, rotating equipment, fire, explosions, natural phenomena, steam, heat and cold, confined spaces, lasers, compressed gas, hazardous materials handling, etc. There are no unique hazards associated that are not addressed in a safe and efficient manner.

Table 4.2 The Risk Matrix

Consequence
Level

High ^(Note 1)	Low Risk – Acceptable	Medium Risk- Unacceptable	High Risk- Unacceptable	High Risk- Unacceptable
Medium	Extremely Low Risk - Desirable	Low Risk – Acceptable	Medium Risk- Unacceptable	High Risk- Unacceptable
Low	Extremely Low Risk - Desirable	Extremely Low Risk - Desirable	Low Risk – Acceptable	Medium Risk- Unacceptable
Extremely Low	Extremely Low Risk - Desirable	Extremely Low Risk - Desirable	Extremely Low - Desirable	Low Risk – Acceptable
	Extremely Unlikely (<10 ⁻⁴ /y)	Unlikely (Between 10 ⁻⁴ /y and 10 ⁻² /y)	Anticipated Medium (Between 10 ⁻² /y and 10 ⁻¹ /y) ^(Note 2)	Anticipated High (Above 10 ⁻¹ /y) ^(Note 2)

Likelihood of Occurrence

Note 1: Definition of Consequence Levels -

- Extremely Low: Will not result in a significant injury or occupation illness or provide a significant impact on the environment.
- Low: Minor onsite with negligible or no offsite impact. Low risk events are events that may cause minor injury or minor occupational illness or minor impact on the environment.
- Medium: Medium risk events are events that may cause considerable impact onsite or minor impact offsite. Medium risk events may cause deaths, severe injuries or severe occupational illness to personnel or major damage to a facility or minor impact on the environment. Medium risk events are events from which one is capable of returning to operation.
- High: High-risk events may cause serious impact onsite or offsite. High-risk events may cause deaths or loss of facility/operation. High-risk events may cause significant impact on the environment.

Note 2: 10CFR835 may require limits that are more stringent for anticipated events.

4.3. General Approach to Risk Minimization

Hazard identification produces a comprehensive list of hazards present in a process or facility, and the screening phase removes all hazards that are below a threshold of concern, or that are covered by recognized industrial codes and standards. The hazards that are “screened out” do not need to be studied in detail because their risks are already well understood and acceptable. This process is a creative, multi-person examination of the processes, operations and experiments related to C-AD facilities. A hazard is a source of danger with the potential to cause illness, injury or death to personnel, damage to an operation or cause environmental damage.

For each screened hazard retained for further detailed hazard analysis, the unmitigated risk is first evaluated in terms of likelihood and consequence. This evaluation is performed using professional engineering judgment based on machine and experiment design and operating history. This places the hazard on the risk matrix (see Table 4.2). The following assumptions govern the determinations of unmitigated risk:

- The unmitigated risk does not include safety or control systems.
- Assigned frequencies are based on engineering judgment.
- Assigned consequence can be qualitative, but must be conservative.
- If the unmitigated risk is extremely low, then the analysis can stop at this point. Otherwise, one proceeds to the evaluation of mitigated risk as described below.

The unmitigated risk is reevaluated considering the preventive and mitigating factors in place that would either reduce the consequence or reduce the frequency. This should move the location on the risk matrix based on assumed conditional probabilities of failure for the mitigating systems. At this point, the mitigated risk should be either low or extremely low. For

low risk, the evaluation of the hazard is reviewed to determine if there are additional preventive or mitigating features that could be credited to bring the risk to extremely low. The last step is to determine if it is necessary to designate any Safety Significant equipment, make commitments for formal administrative controls, or specify limits for operation.

The purpose of Safety Significant designation is to highlight a minimum number of structures, systems or components needed to ensure safety. The number of designated Safety Significant items and administrative controls and limits must be minimized so that they can be treated specially and considered for incorporation in the Accelerator Safety Envelope (ASE), appropriate procedures and/or quality assurance documents.

If the unmitigated consequence is fatal for one or more persons or a significant environmental impact can occur, then a Safety Significant designation, in general, should be made. If there are several mitigating or preventive features, and any single one can control the hazard adequately, then it may not be necessary to designate a Safety Significant feature.

Table 4.2 allows binning of the hazardous event by its risk, which is a combination of the consequence of the hazardous event and its likelihood of occurrence. Some of these combinations are deemed acceptable, meaning these lower risk bins are adequately addressed by the qualitative hazard evaluation process. Other, higher risk bins are labeled unacceptable because the accidents within these bins require additional quantitative analysis to determine the true mitigated risk.

4.4. Risk Minimization Approach for Radiation Hazards

The risk of a serious radiation injury at BNL accelerators and experiments is insignificant. However, for radiation exposure it customary to go beyond the scope of Hazard Analysis to demonstrate that transient events, such as credible beam faults, do not cause annual radiation dose goals or requirements to be exceeded. The special status of radiation hazards is exemplified in the As Low As Reasonably Achievable (ALARA) requirement in the BNL Radiation Control Manual that exposure to radiation is to be minimized and driven as far below the statutory limits as is practicable. Some areas are controlled access areas. These areas (Controlled Area, Radiation Area, etc.) are established to control the flow and behavior of workers in each area such that workers receive the minimum radiation exposure coincident with operating and maintaining the facility, which is the risk, to achieve its authorized research mission, which is the benefit. These areas are set with the expectation that radiation levels will not exceed certain specified maxima depending on the type of zone. The designated area maxima will be satisfied considering both the base level of residual radiation fields and the integrated effect of the short bursts typical of credible beam faults. The C-A Operations Procedure Manual, in compliance with the BNL Radiation Control Manual, lists the different areas including the required controls for minimizing exposure to external radiation. Significant contamination and internal uptake of radionuclides at C-AD facilities is extremely unlikely and further analyses of these issues are not necessary, and are documented in a [Technical Basis for Bioassay](http://www.rhichome.bnl.gov/AGS/Accel/SND/Bioassay/BioassayTechBasis.doc).¹

4.5. Hazard Identification and Hazard Analysis

¹ <http://www.rhichome.bnl.gov/AGS/Accel/SND/Bioassay/BioassayTechBasis.doc> Technical Basis for Bioassay Requirements, Collider-Accelerator Department, January 2001.

This section describes the hazard identification and qualitative hazard analysis for each of the major portions of the C-AD accelerators and experiments: injectors, accelerators, beam transport systems, beam stop systems, targets, support buildings, power supply buildings, cooling water systems, cryogenic systems, vacuum systems, shielding and instrumentation systems. The results of the hazard identification and analyses are given in [Appendix 9, Qualitative Risk Assessment](#).

The hazard identification process examined the C-AD facility processes, operations and maintenance that could result in a source of danger with the potential to cause illness, injury or death, damage to operations or environmental damage. The facilities design documentation, BNL conventional and radiological safety requirements, facility walk downs, C-A Operating and Emergency Procedures, and discussions with engineering staff, experimenters and safety professionals were utilized to conduct the detailed hazard identification and hazard analysis.

4.5.1. Conventional and Environmental Hazards

A review of all safety and health issues related to C-AD facilities leads to the conclusion that fire (including explosions), radiation, oxygen deficiency hazards from large quantities of inert gases and electrical hazards require further safety analysis, which considers the preventive and mitigating facility design features. Documentation of the hazard screening is found in [Appendix 9](#).

Pressure and vacuum vessels, use of toxic, hazardous and biological materials, use of small quantities of flammable/inert/cryogenic gases/fluids, noise, hoisting/rigging, lasers, rotating equipment, heat and magnetic fields are considered routine activities. The risks from

these activities are maintained acceptable by compliance with the requirements of the BNL Standards Based Management System (SBMS) Subject Areas and the C-A Operations Procedure Manual. When required, these hazards undergo review by the appropriate BNL or C-A committee or they undergo review by C-A ESHQ Division specialists during the work planning process, as indicated by C-A OPM or SBMS requirement.

Electrical safety is a serious and complex subject, which is controlled by trained and experienced C-A and BNL staff engineers, operators, technicians and maintenance personnel. A full description of the electrical safety requirements that assure electrical safety is given in the BNL SBMS. At times access to the injectors, accelerators, transport lines, target areas and the collider is allowed when the magnets are powered. However, access to these areas is always controlled and limited to properly trained individuals. A C-A OPM procedure and an approved working hot permit cover access to these areas by trained and authorized C-A support staff to investigate problems.

Static or fringe magnetic fields that are present in the facility magnets do not warrant special controls other than appropriate warning signs and training of personnel who have access to the areas in accordance with the requirements of the BNL SBMS.

A list of chemicals used in the C-A facilities, the annual quantity used and the manufacturer's Material Safety Data Sheets are maintained in accordance with the BNL Chemical Safety Program. Required reviews of the conventional safety aspects of the C-A facilities shows that use of these chemicals does not warrant special controls other than appropriate signs, procedures, appropriate use of personal protective equipment, and hazard communication training, all of which have been implemented. Reviews are carried out before work begins, via the work planning process.

With regard to environmental impacts, the effluent hazards include generation of ^3H and ^{22}Na in the earth shielding, which could potentially contaminate the ground water, and generation of short-lived radioactive gases in the air in the accelerator rings, transfer lines, tunnels and target caves/rooms. Both of these are addressed in this Chapter of the report, and these hazards have been eliminated or controlled by design. When required or at the discretion of management as a best management practice, Suffolk County Article 12 Code is followed in the design of cooling water systems and piping that contain tritium, sodium and other radionuclides. Diversion of radioactive liquid effluent from the sanitary waste system to a hold-up system, or hold up of radioactive liquid in C-A sumps, occurs in order to allow retention and sampling before disposal. Air emissions from C-AD facilities are negligible since the potential activation products are sufficiently low; that is, much less than 0.1 mrem/year to the public, to assure doses are ALARA. Results of environmental monitoring and details on exposure pathway analysis are found in the annual BNL Laboratory Environmental Report produced by the BNL Environmental Services Division.

4.5.2. Radiation Hazards

The BNL accelerators and experimental beam lines have been in operation for over 45 years providing protons and polarized protons for the high-energy physics program, and in addition, for the past 15 years, the accelerators have been providing heavy ions for the nuclear physics and NASA programs. Among the three operating modes of the AGS, high flux unpolarized proton beam, polarized proton beam and heavy ion beams, the high flux unpolarized proton operation represents the greatest ionizing radiation hazard because they can provide the

highest intensity beam. Fault calculations for shielding and activation are based on fluxes associated with unpolarized protons. For radiation dose calculation purposes, each nucleon in a heavy-ion nucleus, either proton or neutron, is treated as an independent high-energy particle.

There is a great diversity in the type and energy in the ion beams used at the C-AD facilities. The primary beam is only present when the machines are operating. Before interacting, the accelerated beam is essentially monoenergetic, consisting of only one particle type. Passage through the accelerator equipment, experimental equipment or thin shielding leads to the development of electromagnetic and hadronic cascades, which produce many particle types, distributed over a wide range of energies. As the beam energy increases, a greater diversity of secondary particles exists in the primary area radiation fields. Inelastic spallation reactions become significant at energies above ~ 1 to 3 GeV. Accelerated and/or circulating beam losses occur as the beam changes direction, during beam injection into and beam extraction from a machine, at collimators and when the beam passes through transition energy (in the AGS and RHIC only). As these losses occur when the machine is operating, the problems of radiation protection outside the shielding are dominated by photons, neutrons, and for primary energies greater than ~ 10 GeV, muons. Typically, the neutron dose to individuals is less than 10% of their total annual dose. Experimenters and operating personnel who are near the shielding during machine operations receive the higher neutron doses.

The primary ion beams, secondary pions and neutron beams, and scattered particles induce radioactivity in the machine components, targets, collimators, beam scrappers and dumps, shielding (including soil), cooling water and nearby equipment. The interaction of the hadronic beam with these components produces an inelastic cascade. The particles produced in the materials during the spallation are followed by the evaporation of nucleons from the excited

residual nuclei. The full spectrum of isotopes from the original target material nucleus down to tritium may be produced, but in practice only a small number of products are important because of the cross-section values and radioactive half-life values. This volumetric activation within solid materials requires radiation surveys and radiation controls during entry into these areas following machine shutdown for inspection, maintenance or repair activities. The residual radioactivity produced in cooling water is reduced by passing the water through filters and deionizers, which reduces most activation products except for tritium. With the exception of targets, collimators, beam dumps and scrappers, or machine injection and extraction components, the specific activity is not high. Because of the significantly longer mean free path between interactions, the extent of the activity is widespread, dilute and dispersed; unlike activated materials at reactor facilities. This fact greatly reduces the potential for significant contamination issues at C-A facilities.

Muons arise from the decay of pions and kaons, either in secondary particle beams or in the cascades produced by high energy hadrons. Muons are weakly acting leptons that deposit energy in materials by electroweak interactions, or ionization with atomic electrons and can only be removed by ranging them out. For example, at 30 GeV, the muon range is ~80 m in soil, ~60 m in concrete and ~20 m in iron. They can have an energy spectrum that varies up to the energy of the parent pions. Thus, shielding design for muons completely dominates the forward shielding requirements. Muon dose is measured by use of standard health physics instrumentation, because they are similar to electrons in every respect, including quality factor, except for their heavier mass.

The principal radiation hazards at C-AD facilities derive from the primary beam flux and duty cycle of the machine. Listed in order of importance, these hazards include:

- Inadvertent exposure of workers to primary beam.
- Exposure to prompt secondary radiation created by primary beam losses during normal operation or episodes of abnormal losses, including areas near labyrinths and penetrations.
- Exposure to residual radiation induced in machine components such as beam scrappers, beam dumps, collimators, extraction magnets, targets, etc.
- Inadvertent release of activated cooling water to the environment.
- Inadvertent release of radioactive contamination to groundwater by allowing rainwater to leach through activated soil shields.
- Exposure to activated air from primary and secondary beam.
- Skyshine

4.5.3. Source Terms

4.5.3.1. Primary Beam

Primary beam is the ion beam that has not yet interacted with materials and which can cause a whole body dose equivalent rate of more than 50 rem/hr, up to lethal dose. The access controls systems (ACS and PASS) prevent exposure of personnel to primary beam. For direct exposure to the primary beam particles, the only distinction between protons and heavy ions concerns the total mass stopping power and quality factor. Direct exposure is an event against which the maximum level of security is provided in the primary beam areas of C-A facilities. Safeguards against these conditions are provided in accordance with the C-A criteria for monitoring and interlocking of radiation areas. These criteria are specified in the C-A OPM,

Section 9.0 series. To simplify safety analyses, in many instances the heavy ions are treated as an independent assembly of nucleons with a beam flux equal to the particle flux times the atomic mass number.

The probability of unsafe failure of the access controls system that would allow an overexposure from primary beam is so low² that this hazard is not credible and further analysis is not performed.

4.5.3.2. Prompt Secondary Radiation in Areas Outside Primary Beam Shielding

In estimating the degree of radiation risk, shielding design assumes the routine and maximum operating beam for each portion of the facility as indicated in Tables 4.5.3-1 through 4.5.3-X. The shield is designed to mitigate the greatest radiation hazard, which is unpolarized protons. Thus, the shield is more than adequate for protection against polarized proton or heavy ion loss because their intensity and/or individual nucleon energies are much less by comparison.

Radiation levels from routine loss of flux have been estimated for locations around the C-A complex using Monte Carlo codes or simple analytical formulas as given below. Monte Carlo codes approach the solution as a succession of individual processes rather than in terms of global physical quantities. Making a mathematical experiment that is equivalent to the real physical situation simulates the cascade. Particles in the cascade are tracked from interaction to interaction. The events may be, for example, elastic or Coulomb scattering events, inelastic

² D. Beavis, Failures in the PLC Based Radiation Safety Systems, October 31, 2000. D. Beavis, Frequency of Interlock Testing, November 6, 2000. D. Beavis, Estimation of Time to Loss of Protection-The D-Downstream Gate, November 13, 2000.

nuclear events in which any variety of secondary particle may be produce, absorption followed by decay, etc. The processes and particle production are randomly selected using appropriate probability distributions, which are either known or well approximated. At any point in the Monte Carlo simulation, any required macroscopic physical quantity may be scored (i.e., energy, fluence, absorbed dose, stars, etc.). When a sufficient history of events has been obtained, the expected value of each parameter may be obtained to the required statistical accuracy. For many areas, which have been studied extensively with beam faulted in a controlled fashion, results are reported directly.

For high energy particles, 1 GeV or greater, the following analytical formulas are used³:

$$H = 1.8 \times 10^{-5} S_P E_0^{0.76} e^{-\Sigma\zeta} / (R^2 (\theta + 35/\sqrt{E_0})^2)$$

for a point source, and

$$H = 2.7 \times 10^{-5} S_L E_0^{0.76} e^{-\Sigma(\zeta/0.94)} / (R (\theta + 35/\sqrt{E_0})^2)$$

for a line source.

In these equations, the symbols mean:

H = lateral dose equivalent, mrem

E₀ = primary proton energy, GeV

S_P = number of protons lost at a point, p

³ A. H. Sullivan, A Guide to Radiation and Radioactivity Levels Near High Energy Particle Accelerators, Nuclear Technology Publishing, Ashford, Kent, England, 1992. Section 2.1.

S_L = number of protons lost per unit length, p/m

$\zeta = d/\lambda$

d = shield thickness, g/cm²

λ = high energy attenuation mean free path for shield material, g/cm² (Table 1.3 of Sullivan text⁴)

R = distance from beam loss to dose point, m

θ = angle from loss to dose point, degrees (90° is assumed based upon facility experience during fault studies)

For high energy particles, less than 1 GeV, the following analytical formulas are used⁵:

$$H = 2 \times 10^{-5} S_P E_0^{0.76} e^{-\Sigma\eta} (1 - e^{-m}) / (R^2 (\theta + 40/\sqrt{E_0})^2)$$

for a point source, and

$$H = 3 \times 10^{-5} S_L E_0^{0.76} e^{-\Sigma(\eta/0.94)} (1 - e^{-m}) / (R (\theta + 40/\sqrt{E_0})^2)$$

for a line source.

In these equations, the symbols mean:

H = lateral dose equivalent, mrem

⁴ Iron is transparent to low energy neutrons and a value of 200 g/cm is used for computations involving a pure iron shield.

⁵ A. H. Sullivan, A Guide to Radiation and Radioactivity Levels Near High Energy Particle Accelerators, Nuclear Technology Publishing, Ashford, Kent, England, 1992. Section 2.2.

E_0 = primary proton energy, GeV

S_p = number of protons lost at a point, p

S_L = number of protons lost per unit length, p/m

$\eta = d/(\lambda(1 - 0.8 e^{-k}))$, where $k = 3 E_0$ (correction for variation of high energy λ at < 1 GeV)

d = shield thickness, g/cm²

λ = high energy attenuation mean free path for shield material, g/cm² (Table 1.3 of Sullivan text)

$m = 3.6 E_0^{1.6}$ (exponent used in the $(1 - e^{-m})$ term, which corrects for the fact that, when < 1 GeV, some of the incident protons will range out in the target material from ionization events before experiencing an inelastic interaction)

R = distance from beam loss to dose point, m

θ = angle from loss to dose point, degrees (90° is assumed based upon facility experience during fault studies)

Linac

For the Linac, the source term is a continuous loss during operation of 0.1% uniformly distributed as a line source from 10 MeV to 200 MeV along the Linac centerline. The ASE Safety Limit for protons is 9×10^{17} GeV-nucleons/h or 1.25×10^{15} protons/s at 200 MeV. The present ion source configuration limits the actual Linac output to 33 to 35 mA per pulse with a ~500 μ sec pulse width and a ~6 Hz beam width (6.4×10^{14} protons/s). The distance involved is ~135 meters so there may be a line source of 4.7×10^9 protons/m/s with the 0.1% loss rate. The earth fill over the 200 MeV proton transfer line to the Booster, the LTB, is 5.4 m, with a transverse rise over run of 1 to 3 for the berm. Thus, the shield thickness at ground level is 16.2

m. The Linac enclosure itself provides 0.61 m of concrete thickness overhead and on the sides at the 200 MeV end. At the low energy end, 10 MeV, the thickness of the overlying earth is 3 m, and the wall and roof of the Linac enclosure is 0.52 m. The earth shield and concrete enclosure thickness increases as proton energy increases along the length of the Linac. At the end of the Linac tunnel, the 200 MeV proton beam splits to provide a maximum allowable flux of 1×10^{14} protons/s to Booster or AGS with the remaining flux transported to BLIP.

In addition to the LTB, the Linac may inject directly into the AGS through transport along the High Energy Beam Tunnel (HEBT). The earth shield over HEBT is 3 m thick with a transverse rise over run of 1 to 2, thus the shield thickness at ground level is 16.2 m. The area outside the HEBT is a locked and fenced enclosure, posted as a Radiation Area during Linac running. This protects personnel from a potential beam fault dose equivalent rate of about 3.2 rem/hr.

The penetrations in the Linac include the tank 1 gate or tunnel entrance, many 40 cm transmission line holes, many 60 cm vacuum lines, many 60 cm cable trays, many 15 cm cable sleeves, and two bricked-up 1.8 m x 2.4 m access ports for equipment. The transmission line, cable trays, cable sleeves and vacuum penetrations do not give direct line of sight to the tanks, which contain the beam. The walkways in Building 930 along side the Linac are Radiation Areas.

The penetrations in HEBT include a plug door, many 15 cm cable sleeves, two 60 cm cable trays, one 30 cm cable opening, the LTB - Booster penetration, the HTB - Booster penetration, the AGS - HEBT door and labyrinth, a 60 cm x 120 cm airshaft, and two 7 cm cable penetrations. The cable penetrations and the airshaft do not give direct line of sight to the beam line.

The maximum credible unplanned loss is complete loss of the beam at any single point at the maximum energy for a short period. This is termed a "fault" condition throughout the text of this report. In appropriate areas, fault levels are detectable by radiation monitors instantaneously, and if interlocked, the beam will shut down within 9 seconds⁶. It is conservatively estimated that three full energy beam spills may occur within this period of 9 seconds. For areas where a fault may produce more than 20 mrem per fault, a system of access controls such as barriers and locked fences are used and the area is upgraded to one of several types of radiation controlled areas as defined in the C-A OPM Section 9.0 series.

⁶ G. Bennett to D. Beavis, RSC Chairman, "Chipmunk Response Time," BNL Memorandum, October 9, 1991.

Table 4.5.3.a Summary of Routine and Faulted Beam Loss and Radiation Levels for Linac (200 MeV Protons)

Shield Type or Loss Point (2 m air assumed in addition to the shielding)	Area of Interest	Routine Dose Equivalent Rate (0.1% loss rate or 4.7×10^9 p/s-m) mrem/h	Fault Dose Equivalent ⁷ per Linac Pulse (6.4×10^{14} p/s; ~6 Hz) mrem/pulse (mrem/h)
Calculation:			
0.6 m concrete, 5.4 m earth	Linac Tunnel Top	1.3×10^{-6}	9.8×10^{-6} (0.2)
0.6 m concrete, 3 m earth	HEBT Top	6.9×10^{-3}	1.5×10^{-1} (3240)
0.6 m concrete, 6 m earth	HEBT Side	1.6×10^{-7}	2.7×10^{-6} (0.1)
1.2 m concrete, 3.3 m earth	Linac Equipment Bay	1.5×10^{-4}	4.5×10^{-4} (10)
Fault Studies⁸			
Outside on Berm:			
Beam at HEBT Stops	HEBT Top (outside on berm)	-	1.3×10^{-3} (28)
Beam at HEBT Stops	Blip Pump House Gate (outside on berm)	-	2.7×10^{-3} (58)
Beam at HEBT Stops	In BLIP Pump House	-	4.9×10^{-2} (1058)
Beam at HEBT Stops	AGS / HEBT Gate	-	2.5×10^{-1} (8400)
Inside Enclosures:			
Beam Near TTB Penetration	HTB Enclosure ⁹	-	1.2×10^{-1} (2590)
Beam Near LTBT Penetration	Booster Enclosure	-	2.6×10^{-3} (56)
Beam Near HTB Penetration	Booster Enclosure	-	7.1×10^{-3} (153)

The original 750 KeV Cockcroft-Walton described by Wheeler and Moore in "Shielding of the 200 MeV Linac," AGSCD-10, was replaced by a more reliable, low maintenance 750 KeV Radio Frequency Quadrupole (RFQ) in December 1988. This preinjector is equipped with a rotationally symmetric magnetron source, fast beam diagnostics, and a fast beam chopper, which

⁷ In appropriate areas, fault levels are detectable by radiation monitors instantaneously, and if interlocked, the beam will shut down within 9 seconds. It is estimated that 54 full energy beam spills may occur within this 9-second interval at a design repetition rate of 6 hz. For areas where a fault may produce more than 20 mrem per fault, a system of access controls such as barriers and locked fences are used and the area is upgraded to one of the several types of radiation controlled areas as defined in the BNL Radiation Control Manual.

⁸ D. Beavis, Summary of Linac Fault Studies 1 – 3, HTB Safety Analysis Report, Appendix 7.7 (September 1991).

⁹ Small area source that is less than 1000 cm³.

removes undesirable beam between AGS bunches that are otherwise dumped in the AGS Ring. The fast beam chopper removes H^- particles at 750 KeV, particles that would otherwise be lost at AGS energies.

The 35 KeV transport line is 1.2 m long and it leads into the RFQ. The RFQ is 1.6 m long and experience indicates 85% transmission of the beam at the exit of the RFQ. The output of the RFQ is ~ 80 mA with a design output up to 100 ma. The RFQ currently operates at a ~ 6 Hz repetition rate (design of 10 Hz), and the beam pulse width is variable depending upon the needs of the AGS (~ 0.5 ms). From the exit of the RFQ, the beam is transported to the Linac entrance with loss occurring in the aperture of the first beam buncher at an energy of 750 KeV. Eighty to 85% of the beam at the Linac entrance is captured and accelerated to 200 MeV. The current configuration allows the Linac to operate with an output up to 33 to 35 mA (4.7×10^{14} p/s), although the capability is there to reach higher currents in the future, about 50 mA (7×10^{14} p/s), if the ion source is upgraded.

Based on the above performance characteristics, about 8.5×10^{13} p/s are lost in the accelerating cavities of the Linac. Most of this loss is in the first cavity, which accelerates protons to 10 MeV. The lost protons stop on the copper surfaces of the drift tubes and produce x-rays.

Loss of protons with energies above 50 MeV in the Linac, LTB or HEBT regions produces neutrons that may reach nearby facilities. The earth shield in the Linac area rises proportionately with proton energy, up to 5.4 m when the protons reach 200 MeV. Following the Linac accelerating cavities is the LTB line that is located in the first 15 m of HEBT. Linac beam may be transported into the Booster or directly into the AGS through the full HEBT line, bypassing the Booster. Shielding over the HEBT transport line is 3 m earth and 0.6 m concrete. The mechanisms of beam loss in the Linac, LTB or HEBT are two kinds: 1) loss of longitudinal

stability and 2) failure of the magnet system. These failures may give rise to total beam loss that is normally detected after several lost pulses and corrected by the operators. Transient phenomena may give rise to a continuous low-level loss of beam. While a 0.1% uniformly distributed loss is the ideal condition for the Linac, significantly greater losses are acceptable based on the actual thickness of the HEBT shielding and the proximity of other facilities around the Linac.

The limiting continuous loss in HEBT is about 2%. This is based on 25 mrem per year to personnel in the BLIP Facility, which is closest to the HEBT line, and which is occupied about 1000 hours per year. The HEBT line was originally used for direct injection of protons from Linac to AGS. Because the Linac currently injects into the Booster, the HEBT line is only used for test beams for a fraction of the time when the Linac operates. Assuming a distributed loss over HEBT line, a 36 m line source, a flux of 1×10^{14} protons/s to Booster or AGS, a lateral distance between BLIP and HEBT of 15 m, and loss distributed in time over 1000 hours; the line source equation indicates a maximum allowable loss rate of 5.5×10^{10} p/s-m during 1000 hours of operation. This is equivalent to a 2% beam loss continuously during the proton running period. A similar analysis was made for continuous loss in the LTB.

Fault studies (see Table 4.5.3-1) indicate that a point loss calculation for total beam loss in HEBT overestimates the measured dose equivalent rate outside the shield on the top of HEBT. This may be due to spreading out of the beam during an actual loss, which does not agree with point source geometry used in the calculation, or may be due to not accounting for shielding offered by magnets and beam components. In general, point source calculations are considered upper estimates since they are difficult, if not impossible, to achieve.

Within the BLIP Pump House are cooling lines containing water activated by primary beam losses in the HEBT beam stop. Very short-lived dissolved radioactive gases are in the water, which give rise to a photon flux in the Pump House that adds to the dose equivalent from neutrons arising from primary beam losses.

XXXXThe polarized proton beam originates as a negatively ionized vertically polarized hydrogen beam from a polarized ion source. These H⁻ ions are injected into an RFQ at 20 KeV and accelerated to 760 KeV. The beam is transported through the Low Energy Beam Transport line (LEBT) through two 60° bends into the Linac where it is accelerated to 200 MeV. The 20 KeV beam accelerates to 760 KeV from the RFQ with 40 μA reaching 200 MeV. The pulse width (FWHM) is 0.5 ms and the repetition rate is every two seconds, which corresponds to a polarized proton flux of 6×10^{10} p/s. This flux is several orders of magnitude less than unpolarized protons.

An x-ray hazard along the length of the Linac rf tanks exists whenever a spark occurs. Exposure rates near the tanks at a level of 1 R/h have been observed during normal operations. This area is on restricted access during maintenance periods and requires training and a self-reading dosimeter for entry. Even though entry through the Linac Tank 1 gate ensures proton beam is interlocked off, the rf may be reset from inside the gate for testing purposes. In addition to training in the hazards associated with this area, a series of fluorescent lights along the tanks warns personnel that rf radiation is present.

Tandem and TTB

The TTB shield and the TTB current monitoring device are designed to mitigate the greatest radiation hazards from low-mass ions. The shield alone is more than adequate for protection against high-mass heavy-ion losses because heavy-ion beam intensity and/or individual nucleon energies are much less by comparison.

To date, the beam accelerated in RHIC has not begun to approach that of the “mature machine”; however, the needs of RHIC for future running were adopted. Deuterons in RHIC were not explicitly considered, but one assumes that explicit proton numbers used for “unfolding” the nucleon-nucleon effects in heavy-ion collisions are suitable. Under this assumption, the total annual deuterons are about 7×10^{17} . This accounts for normal beam losses and deuteron beam tuning in Tandem, TTB, Booster, AGS and AtR.

When the TTB line is delivering beam to downstream users, a 10% beam loss has been observed. No specific points of chronic loss have been identified, and the distribution of these losses is not known. When the TTB line itself is being tuned, beam loss is inherent in the tuning process as wire chambers and Faraday cups are inserted at various places in the line. Adding these losses gives a total loss estimate at a single point of about 2×10^{16} deuterons per year. The maximum incremental loss at a single point was estimated to be about 4.5×10^{13} deuterons in one hour.

The normal running current in the TVDG accelerator room is planned to be 67 nA of deuteron beam at 12 MeV. The normal terminal voltage is planned to be 6 MV. For a full-energy beam fault, radiation levels from deuterons could fault to about 50 rem/h at one foot at 0° from a 30 MeV deuteron beam that would result from a voltage fault of 15 MV. For a full-intensity beam fault, the radiation level could fault to 230 rem/h at 1 foot at 0° if the current is intentionally tuned to maximum 10 μ A. Thus, dual redundant interlocks are required in the

TVDG accelerator room. It is noted these fault conditions require two events: an intensity or voltage fault and stopping the beam at a single point. These radiation levels are summarized in Table 4.5.3.b.

Table 4.5.3.b Calculated Radiation Levels in the TVDG Accelerator Room and the TTB (Deuterons)

Loss Description	Deuteron Current	Terminal Voltage	Instantaneous Dose Equivalent at 1 foot at 0°, rem/h
TVDG Normal Beam, Point Loss (single fault)	67 nA	6 MV	1.5
TVDG Full Energy Beam, Point Loss (double fault)	67 nA	15 MV	50
TVDG Full Current Beam, Point Loss (double fault)	10,000 nA	6 MV	230
TTB Normal Beam, Anticipated Beam Loss (routine loss)	6.7 nA or 10% in transit to RHIC (4.5×10^{13} deuterons for one hour at a point)	6 MV	0.15
TTB Normal Beam, Point Loss (single fault)	67 nA	6 MV	0.04
TTB Full Current Beam, Point Loss (double fault)	200 nA	6 MV	1.5
			4.5

Booster

Among the three operating modes of the Booster, which are high flux unpolarized proton beam, polarized proton beam, and heavy ion beams, the high flux unpolarized proton operation represents the greatest ionizing radiation hazard. With the exception of the shielding over the first dipole following the stripper for heavy ions, all calculations for shielding and activation are based on fluxes associated with unpolarized protons.

Table 4.5.3.c Summary of Booster Beam Flux and Beam Loss

Parameter	Unpolarized A = 1	Polarized A = 1	Sulfur A = 32	Gold A = 197
Beam Flux (sec ⁻¹)	6×10^{13}	1.5×10^{12}	1.5×10^{10}	3.2×10^9
Injection Loss (sec ⁻¹)	1×10^{13}	3×10^{11}	3×10^8	6×10^7
Injection Energy (MeV/nucleon)	200	200	4.688	1.066
Acceleration Losses (sec ⁻¹)	6×10^{11}	1.5×10^{10}	1.5×10^8	3.2×10^7
Extraction Losses (sec ⁻¹)	6×10^{11}	1.5×10^{10}	1.5×10^8	3.2×10^7
Stripper Losses	NA	NA	1.5×10^9	1.6×10^9
Extraction Energy (GeV/nucleon)	1.5	1.5	0.967	0.35
Maximum Credible Loss at Extraction Energy	1×10^{14}	1.5×10^{12}	1.5×10^{10}	3.2×10^9

For a planned beam loss, the assumption is 50% of the loss occurs at a single point such as the dump/catcher and the remainder uniformly distributes around the Booster Ring. For extraction loss, 80% is lost on the septum and 20% is lost on the first dipole downstream. The maximum credible unplanned loss is complete loss of the beam at any single point at the maximum energy for a short period of time. This is termed a “fault” condition throughout the text. Generally, the only distinction between protons and heavy ions concerns the total mass stopping power from direct exposure to the primary beam particles. This is an event against which the maximum level of security is provided in the primary beam areas of the Booster. In all other instances, the heavy ions are treated as an independent assembly of nucleons with a beam flux equal to the particle flux times the atomic mass number. Safeguards against all loss conditions are provided in accordance with the C-A criteria for monitoring and interlocking of radiation areas.

There is one significant difference in these assumptions from current AGS operating conditions: low injection losses in the Booster. This change is based on installation of a beam chopper in the low energy beam transport of the 200 MeV proton Linac prior to the start of beam commissioning on the Booster. The chopper creates a pulse train in synchronism with the stable

rf buckets for beam acceleration. It prevents beam outside these buckets from being injected in the Ring and then getting lost during acceleration. The result is almost an order of magnitude reduction in injection losses.

The shielding of the tunnel enclosure and the interfaces to the 200 MeV proton Linac and the AGS have been analyzed by Gollon¹⁰, Casey¹¹ and Lessard¹². Sufficient shielding is provided to assure that radiation levels in all areas for normal operating conditions met BNL and DOE criteria. Fault conditions were analyzed to ensure that unacceptable radiation levels are controlled. The types of warning/control systems are consistent with the existing C-A area classifications.

A summary of the results is presented in the following tables with details given in the following text. These computed values are upper limits because it is not possible to lose the beam at a single point.

¹⁰ P. J. Gollon, Booster Tunnel Shield Calculation, Booster Technical Note #66, October 24, 1986, in AGS Booster Project Preliminary Safety Analysis Report, Appendix 7.1, Brookhaven National Laboratory, Upton New York, 11973, December 1, 1987.

¹¹ W. R. Casey, Additional Booster Shielding Calculations, Booster Technical Note #93. September 28, 1987 in AGS Booster Project Preliminary Safety Analysis Report, Appendix 7.2, Brookhaven National Laboratory, Upton New York, 11973, December 1, 1987.

¹² E. T. Lessard, Booster Shield Wall/Door Analysis, March 30, 1989.

Table 4.5.3.d Summary of Booster Flux Loss and Radiation Level Summary

Loss Flux Type (particles/s)	Area of Interest	Nucleon Energy	Routine Peak Dose Rate (mrem/h)	Peak Fault Dose Rate ¹³ (mrem/h) (Maximum Flux)
Injection (1×10^{13})	Booster Tunnel Top	200 MeV	0.0003	30 (4×10^{14})
Injection (1×10^{13})	Booster Tunnel Side	200 MeV	0.00006	0.6 (4×10^{14})
Acceleration (6×10^{11})	Booster Tunnel Top	700 MeV	0.2	2500 (1×10^{14})
Acceleration (6×10^{11})	Booster Tunnel Side	700 MeV	0.04	150 (1×10^{14})
Fault (1×10^{14})	Booster Tunnel Top (4.6m sand)	1.5 GeV	NA	5000
Fault (1×10^{14})	Booster Tunnel Side (6.1m sand)	1.5 GeV	NA	330
Extraction (6×10^{11})	B914 Roof Over Septum	1.5 GeV	7	1200 (1×10^{14})
Extraction (1×10^{14})	Remaining B914 Roof	1.5 GeV	1 to 2	150,000
Studies (1.5×10^{13})	Booster Tunnel Over Dump	1.5 GeV	15	95 (1×10^{14})
Studies (1.5×10^{13})	Fence Near Dump	1.5 GeV	0.2	1.4 (1×10^{14})
Fault (1×10^{14})	AGS from Booster	1.5 GeV	NA	550
Fault (1×10^{14})	AGS Labyrinth. Door from Booster	1.5 GeV	NA	1000
Fault (4×10^{14})	Booster from Linac	200 MeV	NA	240
Fault (1.3×10^{13})	Booster from AGS	28 GeV	NA	1400
Fault (1.3×10^{13})	Booster Labyrinth. Door from AGS	28 GeV	NA	2500
Extraction (1.6×10^9) - Gold	B914 Roof Over Stripper	1.066 GeV	5	10 (3.2×10^9)
Extraction (6×10^{11})	B914 Plug Door	1.5 GeV	2	500 (1×10^{14})
Extraction (6×10^{11})	B914 Man-Gate	1.5 GeV	0.5	120 (1×10^{14})
Extraction (6×10^{11})	B914 North Entrance	1.5 GeV	0.2	50 (1×10^{14})

Planned injection losses are estimated at 1×10^{13} p/s at 200 MeV. Assuming that half of these losses occur at a single point, the dump/catcher, a peak radiation level of 0.3 μ rem/h is produced at the top of the berm and less than 0.06 μ rem/h horizontally. The dump/catcher is shielded internally with one meter of heavy concrete equivalent and externally with 5.5 m of sand. The Booster Ring is shielded less, 4.6 m of sand, when compared to the dump area and the fault flux for 200 MeV protons 4×10^{14} p/s. Therefore, away from the dump area, a fault level of 30 mrem/h at the berm top, and 0.6 mrem/h at the berm side is possible with injection energy protons for a short period of time.

Planned losses during acceleration are 1% or less and occur with an average energy

¹³ Fault levels are detectable by radiation monitors after one pulse. When the fault is detected and stopped after one second, the accidental dose to an individual in unfenced areas is well below the design guideline of 20 mrem.

of 700 MeV. Assuming that half of these are lost at a point, which is the dump/catcher, peak radiation levels are 0.2 mrem/h at the top of the berm and 0.04 mrem/h at the side of the berm. If a point loss during acceleration occurred at full beam flux, 1×10^{14} p/s, the berm top would peak at 2500 mrem/h, and the berm side at 150 mrem/h. Fault losses are typically not at a point and distribute over 10 m or more at these momenta. Radiation levels decrease by a factor of two for a loss spread over 10 m, and by a factor of 30 if losses are spread uniformly around the Booster Ring.

Faults at 100% of the beam at 1.5 GeV at a point for a short period of time result in up to 5,000 mrem/h at the berm top and 330 mrem/h horizontally. Due to these potential levels, the berm is designated as a High Radiation Area and is enclosed by a fence. Access is limited to authorized individuals only.

Planned losses at extraction are 1% and occur at an energy of 1.5 GeV. All of these losses are assumed to occur on the extraction septum (80%) and the first dipole magnet (20%) following the septum inside Building 914. Building 914 was constructed from the decommissioned 50 MeV Linac and has a structural limitation of 1.8 m of soil overhead. Sixty centimeters of iron rising to 2.3 m in the forward direction where space permits reduces the routine exterior radiation level on top Building 914 to about seven mrem/h, which occurs over a 40 m² area. Most of the remaining Building 914 roof is 1 to 2 mrem/h for planned extraction loss conditions.

Since the internal iron shield does not fully enclose the transfer line between the Booster and the AGS, momentary peak levels of 40 mrem/s are possible under full fault conditions at 7.5 Hz or 1×10^{14} p/s. For this reason, the roof area above Building 914 is fenced and secured as a Class III area with possible faults into Class II, and the access gate is configured with a hard-

wired switchgear type relay that interlocks the beam. In addition, redundant radiation monitors are used in this region to interlock the beam and limit the duration of the fault. Based on experience at the AGS, fault levels are detectable by radiation monitors after one pulse. If 1×10^{14} p/s, stop in the region not enclosed by iron, about 40 mrem in one second occurs within the fenced-in region on top of Building 914. If the fault is detected and stopped after one second, the accidental dose to a person would be much less than the design guideline of 20 mrem since the nearest uncontrolled area is 50 feet away.

The first dipole past the heavy ion stripper, which is in the transfer line between the Booster and AGS, requires overlying shielding. Projected energy losses are 1×10^{11} GeV/s for Au ions. Poorly stripped ions are swept out at the first dipole after the stripper. A local iron shield 36 cm thick is installed to reduce exterior levels to less than 5 mrem/h on the roof of Building 914. Fault levels are 10 mrem/h.

During Booster studies, the beam dump can receive the full Booster beam. Studies are normally conducted at a peak flux of 1.5×10^{13} p/s at 1.5 GeV, and studies do not occur more than about 500 h/y. The thickness of the steel dump and the iron shield surrounding it contribute an additional equivalence of 1 m of heavy concrete. The sand berm over the dump is 5.5 m thick and this thickness extends 15 m horizontally from the dump. The external radiation levels over the top of the berm are 15 mrem for one hour of studies and about 0.2 mrem in one hour at the berm fence. Fault levels are seven times these planned levels.

At Building 914, routine occupancy near the inhabitable side of the shield wall or man-gate opening would not occur. Because of possible fault levels of 300 mrem/h for a short period, the inhabitable portion of Building 914 is designated as a Radiation Area, and an alarmed/interlocked radiation monitor is installed. The entrance to Building 914 is 27 m from the

shield wall and man-gate. The routine dose rate at the North Entrance is less than 0.01 mrem/h. Routinely, the highest levels are near the shield wall and man-gate entrance and they are 0.1 mrem/h. These estimates are based on a septum that is unshielded along its side and a 1% flux loss. In fact, the septum has a light-concrete photon shield along side it in order to reduce the residual radiation when passing by or working nearby that would also act as a shield during operations.

At least 2.4 m of concrete shielding is placed at the interface between the Booster tunnel and the 200 MeV high-energy beam transport (HEBT) tunnel of the Linac. One hundred twenty cm of lead block is placed in the Linac in line of sight with the Linac to Booster vacuum pipe penetration. The radiation at the Booster side of the interface shield is less than 0.4 mrem/h assuming a planned loss of less than 1% in the Linac HEBT. A fault loss of the maximum Linac beam (30 ma) at a point in the HEBT line near the interface to the Booster results in 240 mrem/h in the Booster tunnel. Such losses would be detected by the Linac radiation monitoring system, which would automatically turn the beam off. A radiation area monitor is provided in the Booster tunnel near the Booster Linac interface to interlock the Linac beam for levels above 2.5 mrem/h. Based on initial fault studies which indicated maximum fault levels less 35 mrem/h, the radiation area monitor would not be necessary. A repeat of the fault study will occur before we consider the area to be protected adequately by shielding alone.

Multiple redundant lockout of bending magnets in the Linac/Booster transfer line inhibit the direct transfer of Linac beam into the Booster tunnel, unless the Booster tunnel is clear of personnel and secure for normal operation.

Certain special areas, where the side shield is thinner than usual because of space restrictions, such as in the area of the Linac building and Building 914, have concrete or steel

inserts in order to assure at least 6 m of equivalent earth. This keeps levels under normal conditions to less than 0.4 mrem/h.

The side shielding at the interface between the Booster and the AGS, which is the equivalent of 6 m of earth side shielding, is designed so that the two machines can operate independently of each other while the other tunnel is opened for maintenance. This criterion is necessary because the Booster may operate with one type of particle beam (e.g. heavy ions for NASA experiments at BAF), while the AGS is engaged in physics operation with direct injection of another particle beam. Under these conditions, independent access is required. There is a labyrinth passage, joining the AGS and the Booster Rings, with High Hazard Radiation Area security doors at each end. Opening these doors crashes the machines. During Booster operation while the AGS tunnel is open, interlocks on the beam transfer dipole in the Booster extraction channel inhibit the transfer of primary beam to the AGS. The worst credible accident, loss of the Booster beam at the Building 914 wall near the AGS, causes levels in the AGS tunnel to rise to 550 mrem/h for 1 to 2 seconds. The reverse case is operation of the AGS while the Booster tunnel is open for maintenance. For operation of the AGS at a maximum beam flux of 2×10^{13} protons per pulse at 1.5-second repetition rate, the worst case of total beam loss causes 1400 mrem/h in Building 914 for approximately 1 to 2 seconds. Radiation monitors interlocked to each machines operation are provided.

With Booster on, the radiation levels in the extraction area will interfere with the function of these interlocked radiation monitors plus these monitors would serve no purpose. They would have to be removed from the security system during Booster running. One option is not to alter the security system but another location for these radiation monitors. Based on future fault studies, the appropriate location of radiation monitors to protect an occupied Booster extraction

area against AGS faults will be re-examined. For example, radiation monitors on the roof of Building 914 may serve this function adequately.

Transmission from losses in the AGS through the AGS-Booster labyrinth is measured at 4×10^{-5} . Calculations indicate that transmission through the labyrinth is from 8×10^{-6} to 4×10^{-7} for a loss at the mouth of the labyrinth. The measured transmission cannot be directly compared to calculations since losses occurred near the mouth and along the sidewall of the labyrinth in the AGS Ring. Using the measured transmission, the worst-case level is 2500 mrem/h. The reverse, which is the worst-case level at the AGS door to the labyrinth from a loss in the Booster, is 1000 mrem/h assuming that the 4×10^{-5} transmission value applies.

Table 4.5.3.e Summary of Planned Beam Loss in the AGS Ring (Maximum beam flux assumed at 1×10^{14} unpolarized protons per second)

Location and Beam Energy	Spot Loss Near Thick Shield (% of beam flux)	Spot Loss Near Thin Shield (% of beam flux)	Distributed Loss (% of beam flux)
Injection Losses (1.5 GeV)	8	1	1
Transition Losses (7 GeV)	0.9	0.05	0.05
Extraction Losses (27.5 GeV)	0.9	0.05	0.05
Studies Losses (10 GeV)	4.9	0.05	0.05

Table 4.5.3.f Proton Beam Loss and Location in the AGS Ring

Loss Type	Protons Lost per Year	Protons Lost per Meter-Year	Energy (GeV)	Concrete Thickness (m)	Earth and Soilcrete Thickness (m)
Injection ¹⁴	6.6×10^{19}	4.1×10^{18}	1.5	0.3	6.0
Injection ¹⁵	8.2×10^{18}	1.0×10^{16}	1.5	0.3	5.7
Injection ⁶	8.2×10^{18}	5.1×10^{17}	1.5	0.3	4.5
Transition ⁶	7.4×10^{18}	4.6×10^{17}	7	0.3	6.3
Transition ⁷	4.1×10^{17}	5.1×10^{14}	7	0.3	5.7
Transition ⁶	4.1×10^{17}	2.5×10^{16}	7	0.3	4.5
Ejection ⁶	7.4×10^{18}	4.6×10^{17}	27.5	0.3	6.3
Ejection ⁷	4.1×10^{17}	5.1×10^{14}	27.5	0.3	5.7
Ejection ⁶	4.1×10^{17}	2.5×10^{16}	27.5	0.3	4.5
Studies ⁶	4.2×10^{19}	2.6×10^{18}	10	0.3	6.3
Studies ⁷	4.1×10^{17}	5.1×10^{14}	10	0.3	5.7
Studies ⁶	4.1×10^{17}	2.5×10^{16}	10	0.3	4.5

Booster Applications Facility (BAF)

Table 4.5.3.g Summary of Routine, Maximum and Faulted Beam Operating Assumptions for Booster Applications Facility

Quantity	Maximum Value
Annual Energy Flux from Booster SEB	10^{17} GeV in one year
Hourly Energy Flux from Booster SEB	6×10^{14} GeV in one hour
Annual Energy Flux on the BAF Beam Stop	3×10^{16} GeV in one year
Hourly Energy Flux on the BAF Beam Stop	6×10^{14} GeV in one hour
Annual Energy Flux on BAF Targets (0.25 nuclear interaction lengths)	3×10^{16} GeV in one year
Hourly Energy Flux on BAF Targets (1.0 nuclear interaction length)	6×10^{14} GeV in one hour
Maximum, Single Event, Non-routine Point Loss at any Location ¹⁶	6.75×10^{15} GeV

4.5.3.3. Induced Residual Activity

Linac

Tandem and TTB

¹⁴ 16m spot loss assumed

¹⁵ Loss assumed to be uniformly distributed around entire ring (800m)

¹⁶ The maximum, single-event, non-routine point loss is 1.5×10^{14} 5-GeV nucleons/sec for 9 seconds. Nine-seconds is the assumed response time of fixed-area radiation monitors to interlock the beam. Thus, a single-event, high-energy nucleon loss of 6.75×10^{15} GeV is the maximum fault assumption for any location at Booster Applications Facility. It is noted in BNL Memorandum, J. Geller to D. Beavis, RSC Chair, "Time to Chipmunk Interlock for Large Radiation Faults," March 2, 1999 that tests of the internal chipmunk circuitry yield an absolute minimum response time of 0.65 seconds. Nine seconds is taken to include the response time of the external circuitry that includes relays and critical devices.

Booster

BAF

AGS

Fixed Targets

AtR

RHIC

e-Cooler

EBIS

4.5.3.4. Activiated Cooling Water

Linac

Tandem and TTB

Booster

BAF

AGS

Fixed Targets

AtR

RHIC

e-Cooler

EBIS

4.5.3.5. Soil Activation and Groundwater Contamination

Linac

Tandem and TTB

Booster

BAF

AGS

Fixed Targets

AtR

RHIC

e-Cooler

EBIS

4.5.3.6. Activated Air

Linac

Tandem and TTB

Booster

BAF

AGS

Fixed Targets

AtR

RHIC

e-Cooler

EBIS

4.5.3.7.Skyshine

Linac

Tandem and TTB

Booster

BAF

AGS

Fixed Targets

AtR

RHIC

e-Cooler

EBIS

4.5.4. Results of Calculation for Radiation Levels

Booster Applications Facility

An elevation view near the Target Room and beam dump is shown in Figure 4.5.4.a. The prompt radiation at the edge of the berm above the target in the Target Room, which is the point

of minimum shield thickness, was computed using the Tesch formula for 3.07 GeV protons.¹⁷ This dose was found to be 2.42×10^{-17} rem per proton. Table 4.5.3 prescribes a maximum hourly limit of beam interacting on target to be 6×10^{14} GeV, which would result in 4.73 mrem per hour. Averaged over a year, the hourly dose is much less. From Appendix 1 and for a “thick target” the average GeV per hour is 2×10^{13} versus the 6×10^{14} considered above, for a reduction factor of 0.033, or an average dose rate of 0.16 mrem/hr.

The dose on the berm slope shown in Figure 4.5.4.a next to the beam dump was compared to the dose at 90° with respect to the target on the top berm using the CASIM program for high-energy particle *cascade-simulations*.¹⁸ The result was that the dose on the slope is less than at the berm top. Thus, the hourly dose rates at the top of the berm are bounding, even for the situation where no target is in place.

As indicated in Figure 4.5.4.a, upstream of the Target Room the shielding consists of 15 feet of earth. At the edge of the berm here, the Tesch formula gives 4.52×10^{-17} rem per proton. Assuming a 5% inadvertent loss of the maximum hourly limit (3×10^{13} GeV) gives 0.44 mrem/hr. The average hourly dose rate corresponding to a chronic 5% inadvertent loss is a factor of 0.033 less, which is a dose rate of 0.015 mrem/hr. The assumption of a hypothetical 5% loss just before the target is based on experience with the final focusing magnet in a beam line at AGS; however, it is noted that operators monitor losses and are required to reduce beam losses to ALARA levels.

The prompt radiation at the nearest point in the Target Room is estimated by evaluation of the labyrinth shown in Figure 4.5.4.b. The estimate was made using the MCNPX code, as

¹⁷ K. Tesch and H. Dinter, Radiation Protection Dosimetry, Vol. 15 No. 2 pp. 89-107 (1986). See Appendix 1.

¹⁸ The CASIM code overestimates the dose in the forward direction when compared to the actual condition estimated by improved codes such as MCNPX at the GeV energy scale.

described in [Appendix 1](#). The dose at door of the support building, which is the circled 4 in the figure, for 3.07 GeV protons incident on a 12 cm plastic target, which is 0.16 interaction length, is 10^{-18} rem per proton. The maximum hourly dose is obtained by assuming 6×10^{14} GeV on a one interaction length target. It is assumed that neutrons dominate the dose at the support building labyrinth-door. The re-entrant dump design supports this assumption. The resultant maximum dose rate is 0.84 mrem per hour. The average hourly rate assumes a 0.25 interaction length target. Combining this with the average 2×10^{13} GeV per hour gives 0.01 mrem per hour.

Figure 4.5.4.b Labyrinth from Target Room to Support Laboratory

Both the skyshine dose-rate estimate and the groundwater activation estimate, described later in this Report, are sensitive to targeting conditions. The maximum flux values listed in Table 4.5.3 assume that the beam can be incident on either a target or the beam stop 100% of the time. Since this condition was not envisaged at the time of the initial estimates reported in [Appendix 1](#), new revised calculations were made. However, the techniques were not changed, so the reader is referred to [Appendix 1](#) for a more complete description.

The skyshine dose rate was determined by first estimating the number of neutrons greater than 20 MeV emerging from the earthen berm surface, then applying a skyshine formula developed from past measurements made at the AGS. The estimate of the number of neutrons was made from CASIM calculations performed at a 2 GeV incident energy in a simplified approximation of the geometry, a geometry that overestimates the emerging neutrons.

Specifically, the berm was assumed to have a circular transverse cross-section, and the neutrons were summed over a $\pm 45^\circ$ section centered on the beam line. A schematic cross section at the target position is shown in Figure 4.5.4.c.¹⁹

Figure 4.5.4.c Cross Section at Target Position Showing Skyshine Approximation

CASIM estimates were made with both the beam incident on the beam dump and on a 0.25 interaction length plastic target. The worst case was with the target present, where the number of neutrons greater than 20 MeV per 2 GeV proton is 2×10^{-5} . For 1.5×10^{16} 2-GeV protons per year, the skyshine formula from [Appendix 1](#) becomes:²⁰

$$rem / year = \frac{0.125 \times e^{-D/600} \times (1 - e^{-D/47})}{D^2}$$

where D is the lateral distance from the source to the dose point of interest in meters. The closest building that at times is uncontrolled is Building 919 at D = 70 m. At this distance, the computed dose rate is about 0.02 mrem/yr.

Groundwater activation from beam interactions in or near the Target Room is also sensitive to the targeting conditions. Again, new CASIM calculations were made for the beam incident either on a 0.25 interaction length plastic target or on the dump. The transverse size of the beam was also varied.

¹⁹ This is a slightly different approximation than was made in Appendix 1.

²⁰ The calculation in Appendix 1 was performed with a 12 cm. Long Fe target.

The technique for estimating groundwater activation is described in [Appendix 1](#). The time-averaged transport of ^3H and ^{22}Na concentrations from the position of their creation to the water table by the leaching action of rainwater is estimated. This leachate concentration is required to be less than 5% of the drinking water standard as per the [Standards Based Management System](#).²¹ The drinking water standard is 20,000 pCi/L for ^3H and 400 pCi/L for ^{22}Na . If this condition is not met, then geo-membrane liners or caps are required to cover the soil. These caps act like umbrellas to prevent leaching of the radionuclides from the soil to the water table.

The quantity calculated to determine the soil radionuclide content is the CASIM “star density.” This is the interaction density of hadrons above about 47 MeV. Approximately 0.075 ^3H and 0.02 ^{22}Na are created “per CASIM star.” More information is given in [Appendix 1](#).

A search was made for the highest star density in soil. Figure 4.5.4.d shows a plan view of the dump region on the vertical mid-plane. The highest star density was found to be at the point labeled with the circled "4" for a very large beam incident directly on the dump. The value of 2.6×10^{-8} stars/cc-p for 3.07 GeV protons is slightly higher than given in [Appendix 1](#). The total stars per year is obtained by scaling to 1.5×10^{16} 2-GeV nucleons to obtain a star density of 2.8×10^8 stars/cc-year. Using the leaching model described in [Appendix 1](#), this results in a “hot spot” of 706 pCi/L of ^3H and 85 pCi/L ^{22}Na . Since 5% of the drinking water standard for ^{22}Na is only 20 pCi/L, a liner is required over the dump. The ^3H concentration is only 3.5% of the drinking water standard. Another CASIM calculation was performed by simulating an upstream loss by forcing protons to interact over a length of one meter in the beam pipe in a bare tunnel. If chronic loss of 5% of the beam is assumed, the result is a factor of three

²¹ <https://sbms.bnl.gov/standard/1r/1r00t011.htm> Accelerator Safety Subject Area

lower than quoted above. Thus for ^{22}Na , the 85 pCi/L is scaled down to 28 pCi/L for this scenario. It is noted that a liner is installed over the entire beam line from the extraction point at the Booster to the Booster Applications Facility beam dump.

Figure 4.5.4.d Plan View of Target Room Dump Region

The air activation estimate, as the estimate made for prompt radiation at the entrance to the Target Room labyrinth in the support building, was made using MCNPX. The current values were scaled from the results given in [Appendix 1](#). However, one significant change has been noted in the intended operation, namely that the vacuum pipe, which had been thought to exist up to the target, actually terminates 5 feet upstream of the Target Room. The beam path length in air, which was assumed 10 feet in [Appendix 1](#), was therefore increased to 28 feet including the length of the re-entrant beam dump cavity.

With a correction for the target thickness used in the estimate described in [Appendix 1](#), the room-averaged hadron flux greater than 20 MeV from interactions becomes 2.1×10^{-6} per cm^2 per incident 2-GeV proton, and the thermal neutron flux becomes 3.4×10^{-6} per cm^2 per proton. However, the room averaged flux of the incident beam particles increases to 6.8×10^{-6} per cm^2 per proton, which dominates the activation of air.

Given these fluxes, concentrations of various radionuclides are estimated using the cross sections given in [Appendix 1](#). For ^{39}Cl and ^{38}Cl , produced by spallation reactions with the argon in Target Room air, cross sections were estimated from Rudstram. These were included because they are sometimes detected in air samples at BNL accelerators. With the annual 3×10^{16} GeV

per year given in Table 4.5.3, the following annual-activity concentrations averaged over the Target Room volume are computed conservatively ignoring radioactive decay and Target Room ventilation:

Table 4.5.4.a Annual-Activity Concentration Averaged over Target Room Volume and Annual Production Rate of Air Activation Products

Radionuclide of Interest	Volume Averaged Annual-Activity Concentration, Ci/cc	Annual Production Rate, Ci/yr
⁴¹ Ar	2.2×10^{-11}	2.6×10^{-3}
³⁹ Cl	1.2×10^{-16}	1.4×10^{-8}
³⁸ Cl	4.3×10^{-16}	4.9×10^{-8}
³⁵ S	1.4×10^{-15}	1.6×10^{-7}
³² P	9.1×10^{-15}	1.0×10^{-6}
²⁸ Al	7.0×10^{-13}	8.1×10^{-5}
²² Na	5.6×10^{-17}	6.3×10^{-9}
¹⁵ O	6.7×10^{-9}	7.4×10^{-1}
¹⁴ O	2.8×10^{-10}	3.2×10^{-2}
¹³ N	1.6×10^{-9}	1.8×10^{-1}
¹¹ C	7.0×10^{-10}	8.1×10^{-2}
⁷ Be	1.9×10^{-13}	2.1×10^{-5}
³ H	7.7×10^{-15}	8.8×10^{-7}

Given these radionuclide quantities, the dose to the maximally exposed individual of the public has been estimated using the Clean Air Act Code CAP88-PC. The standard BNL site-specific model was utilized with 10-year average wind rose, temperature and precipitation and the most current, CY 2000, population data. The CAP88-PC model is designed to model continuous airborne radioactive emissions that occur over the course of a year. The radionuclides in Table 4.5.4.a were modeled as if they were released in this manner. Aluminum-28 and oxygen-14 are not included in the CAP88-PC radionuclide library and thus are not included in the model. However, the source terms and half-lives of these radionuclides are so

small that their exclusion has no affect on the conclusions of the evaluation. Chlorine-39 and chlorine-38 were also not included because their effect has no affect on the conclusion.

Appendix 4 showed that the dose to the BNL site maximally exposed individual of the public at the northeastern site boundary is 9.7×10^{-6} mrem/yr.²² This dose is six orders of magnitude below the 10 mrem/yr limit specified in 40CFR61, Subpart H, and a factor of ten-thousand times less than the 0.1 mrem/yr limit that triggers the NESHAPs permitting process. Therefore, no application for a permit was required for the Booster Applications Facility and continuous monitoring of the release point is not required.

Normally, the Target Room is ventilated continuously to reduce odors from the biological specimens. The ventilation system will maintain the radionuclide concentrations at insignificant values in the Target Room. If the ventilation is off and irradiations and entries are still made, the dose to an individual who spends an hour in the Target Room would be a small fraction of a mrem. Thus, there are no significant hazards from loss of Target Room ventilation.

AGS

Fixed Targets

RHIC Transfer Line (AtR)

Calculations²³ of the prompt radiation dose in regions exterior to the berm over the AtR have been performed. The calculation assumes beam intensity equivalent to 2×10^{11} protons per bunch, and that 114 bunches are delivered to each collider ring. This is equal to the ASE

²² <http://www.rhichome.bnl.gov/AGS/Accel/SND//SADAppendix4.pdf>, Appendix 4, SAD, G. Schreoder, Booster Applications Facility Facility/Process Radionuclide Evaluation, January 4, 2001.

²³ A. J. Stevens, AD/RHIC/RD-83, Analysis of Radiation Levels Associated with Operation of the RHIC Transfer Line, December 1994.

intensity limit of 2.4×10^{13} protons per ring. The calculation also assumed twice the current regulatory value of the neutron quality factor. Thus, the more realistic estimates for dose (half those presented in the design calculations) are presented in this section.

Most regions of the AtR line experience very small beam loss ($\sim 0.05\%$ of the injected beam at a single point such as a magnet and 0.1% over the entire length of the line). A beam stop is located in the AtR line where the X and Y lines split from the W line. This dump is assumed to absorb 100 times the beam lost in the rest of the line. A summary of the calculation results is given below. The Big Bend Region is the X and Y injection arcs where the magnet elements are “dense”. The Other Regions are upstream of the injection arcs where the magnet elements are “sparse”. In the “dense” magnet regions, the generations of cascade interactions occur spatially closer to each other, thus causing higher peak fluence closer to the original interaction as compared to the “sparse” magnet regions.

Dose Equivalent Rates:

Big Bend Region: 0.13 mrem in an hour

Other Regions: 0.08 mrem in an hour

Annual Dose Equivalent:

	Big Bend Region	Other Regions
Au	138 mrem	81 mrem
Protons	16 mrem	9 mrem
Total	154 mrem	90 mrem

The maximum loss over 10 seconds is of interest for determining the sensitivity of Chipmunk response. The least sensitive area would be “other regions”. For this case, Au is 0.72 mrem/hr and protons are 1.56 mrem/hr.

The computed dose rates on the berm over the AtR are summarized below. Two distinct, credible cases were examined: (1) the loss of full beam on an arbitrary point five times per year which persists for two AGS pulses, and (2) an order of magnitude higher loss than normal (0.5% at a point and 1% over the length of the AtR line for 5% of the collider fills in a year.

Fault Dose Equivalent Rates:

	Big Bend Region	Other Regions
Two AGS pulses or 4.8×10^{12} 28 GeV protons lost at an arbitrary point 5 times/yr	(6.3 mrem/fault) 31 mrem/yr	(3.5 mrem/fault) 17.5 mrem/yr
0.5% point loss for and 1% total loss for 5% of the fills each year	77 mrem/yr	45 mrem/yr.
Total	108 mrem/yr	62.5 mrem/yr

Skyshine, from normal injection operation and faults in the AtR line, was computed to be 0.003 mrem/yr at the closest occupied building (1005S) and 0.0001 mrem/yr at the closest site boundary. Skyshine from the AtR beam dump during set-up and studies was found to be 1.9 mrem/yr at Thompson Road (posted as a Controlled Area during RHIC operations), 0.006 mrem/yr at Building 1005S and 0.00023 at the closest site boundary.

RHIC Beam Stop and Collimators and Groundwater Protection

Both the collimators and beam stops are intended locations for beam loss. The Collider beam stops are located on either side of the 10 o'clock intersection region. They account for about 85% of the total loss of beam energy²⁴. The dose equivalent to the closest site boundary

²⁴ A. J. Stevens, AD/RHIC/RD-48, Radiation Environment and Induced Activity Near the RHIC Internal Beam Dump, November 1992. A. J. Stevens, Estimate of Dose Rate Close to the C-C Dump Core from Induced Activity, August 8, 1995.

from operation of these dumps is <0.5 mrem/year. The areas on the collider berm that are above the dumps are fenced and controlled as Radiation Areas to exclude non-radiation workers.

Skyshine from the operation of the dumps was computed to be 0.4 mrem/yr at William Floyd Parkway (lower in occupied offsite locations) and 1.25 mrem/yr to the closest onsite building (1101), which is inside a Controlled Area.

The primary beam collimators are located on either side of the 8 o'clock intersection region. The dose calculation assumed that 20% of the beam in each ring interacts on the collimator and at most, 10% of the stored beam in an hour²⁵. Because of the radiation levels on the berm following routine and faulted losses, the area is fenced to exclude non-radiation workers. The dose at William Floyd Parkway is <0.5 mrem/yr and to the nearest onsite building (1101) is 0.55 mrem/yr.

e-Cooler

EBIS

XXXXXXInduced Activity in Soil and Groundwater

A very small amount of soil activation will occur in the sand around the Collider Beam Stops at 10 o'clock as a part of routine operation. The calculations show that two principal isotopes, ^3H and ^{22}Na , will be induced in soil within 40 cm of the tunnel wall and floor in concentrations in soil of 2.2×10^5 and 2.8×10^5 pCi/liter/yr, respectively. It should be noted that there are no potable water sources near the Collider Beam Stops. BNL tries to achieve as close to

²⁵ A. J. Stevens, AD/RHIC/RD-113, Radiation Safety Issues Near Collimators, April 1997.

zero environmental impact as possible. To minimize the leaching of induced radioactivity from the soil that surrounds the Collider Beam Stops and collimators, an “umbrella” in the form of a waterproof membrane is placed over the affected areas. Capping the berm in the vicinity of the collimators was completed during the 2002 summer shutdown. The “umbrella” effectively traps the vast majority of induced radioactivity, causing it to accumulate above the water table. This will result in much lower concentrations of radioactivity in the groundwater (<5% by design) than those stated above.

If no cap was installed, a conservative prediction of the possible concentration of tritium and sodium-22 can be made by assuming that approximately half of the total amount of annual precipitation (55 cm of the total of 122 cm annual average) leaches through the most activated portion of these soils, and the remainder of the precipitation is lost due to evaporation or evapotranspiration. Under this scenario, the annual average tritium and sodium-22 concentrations in soil pore water directly below the beam dump areas may be as high as 1.7×10^5 and 2×10^4 pCi/l, respectively. However, the annual volume of water with these concentrations would likely be less than 40 gallons at each beam stop, and there would be significant dilution of this water within a short distance upon entering the aquifer system.

By preventing rainwater infiltration, the tritium and sodium-22 pore water concentrations are predicted to be reduced by a factor of at least 100, to concentrations in the range of 1,700 pCi/l and 200 pCi/l, or 8.5% and 49% of the New York State Drinking Water Standard, respectively. The concentration in the collimator areas at 8 o'clock are approximately five times less than the Beam Stop potential.

From the Beam Loss Scenario (Appendix 8), the total annual energy on the W-Line BeamStop is equivalent to 1.5×10^{14} Au ions per year at 10.4 GeV/u. This is 2.7% of the energy

on either of the two Collider Beam Stops. If one compares the maximum star density in soil per year at the W-Line Beam Stop to either of the Collider Beam Stops, it is 4.5% in the forward direction and 0.08% in the transverse direction. The 4.5% would give 7650 pCi of ^3H per liter at the water table in the same model used for the Collider Beam Stop (Appendix 47). Furthermore, the volume of soil is only about 10 liters in this geometry. Therefore, mitigation at the W-Line Beam Stop was not deemed necessary.

To verify that the operations of RHIC do not impact groundwater or surface water quality, the BNL routine groundwater monitoring program was augmented in the vicinity of the Beam Stop and Collimators with additional monitoring wells, and routine surface water sampling downstream of the Peconic River culvert. The monitoring program began one year before the start of Routine Operation of the Collider. The monitoring plan and assessment of groundwater impacts is shown in Appendix 21.

Internal Residual Levels from Beam Stops ⁸⁴

Induced Activity Near the Beam Stop from Appendix 23:

Cooling Time 1 ft from Marble 1 ft from Exposed Core

1 hr 16 mrem/hr 608 mrem/hr

1 day 5 mrem/hr 150 mrem/hr

Cooling Water Activation And Radiation Dose From Air Activation

Cooling Water Activation

Calculations were performed to assess ^3H production in cooling water used by the

experimental systems. Because the source of beam loss is due mainly from beam-beam interaction, the water is exposed to small flux of secondary particles. The methodology is shown in Appendix 40, and the results are summarized in Table 4-D-1.

TABLE 4-D-1

Estimated ^3H Activity Concentrations

System

pCi/l for 1 Year Running at

Design Luminosity Comment

STAR Magnet <0.23 Main Coils Only

STAR SVT 4.1

STAR TPC 0.20

STAR Electronics <.09 Closest Point Only

PHENIX Magnet 0.18

PHENIX MVD*** 2.2 (Capacity 4.1 Gallons)

BRAHMS Magnet <0.40 0 = 0 at All Points

PHOBOS Magnet 1.1

PHOBOS Silicon 21.8

***Not actually water: FC-25 treated as if it were water.

Air Activation

The calculations and results shown in Appendix 20 and Appendix 9 were scaled to reflect the Beam Loss Scenario in Appendix 8. This increased the results by approximately a factor of two. Air activation would produce 0.03 mrem/yr at the site boundary, if somehow all the activity

were released 250 meters from it. In reality, activated air is released only by natural circulation causing almost all of the very short-lived activity to decay in place. Therefore, the actual site boundary will be a small fraction of 0.03 mrem.

Radiation Dose From Muons

A detailed calculation of the dose impact from muons was provided in the Preliminary Safety Analysis Report. This calculation was updated based on the Beam Loss Scenario, the actual locations of the Limiting Aperture Collimator and the Collider Beam Stop. The initial analysis and update to it are in Appendix 19.

The site boundary muon dose from the Beam Stop at 10 o'clock and collimator at 12 o'clock is estimated to be 0.15 to 0.42 mrem/yr and 0.07 to 0.36 mrem/yr, respectively. Muon dose from the intersection regions is 0.035 mrem.

Radiation Dose From A DBA Collider Fault

The Beam Loss Scenario in Appendix 8 assumes that an uncontrolled loss of a beam at full energy is possible at a location other than at the intended loss point, the Beam Stop at 10 o'clock. In the case of a DBA Collider fault with the ASE intensity proton beam, it is assumed that, for most locations in each ring, half the beam (the equivalent of 1.14×10^{13} 250 GeV protons) is lost at a point and the other half distributed over an extended length of magnets. The entire beam could be lost at an aperture-defining location including the high β quadrupoles. At the super-conducting Tevetron at Fermi National Laboratory the entire full energy beam has been

lost twice in approximately 10 years of running to date, but in both cases the loss was distributed over a long portion of the machine. The maximum credible loss defined here is therefore conservative. The maximum dose, using the method shown in Appendix 15, from a DBA fault to an individual standing at a typical location on the berm was estimated to be 57 mrem. During the commissioning and the first year of operation, the RHIC beam intensity was slowly increased, so that uncertainties in calculations of the dose potential could be determined by a series of fault studies. These fault studies were documented by Stevens²⁶.

Radiation Dose Through Multi-Leg And Straight-Through Penetrations

All the multi-leg penetrations in the Collider, U-, W-, X- and Y-Lines were analyzed with the methodologies by Gollon^{27,28} and recalculations by Stevens^{29,30}. The results were amended to clarify them to the as-built drawings. One exception is the entrance to the U-Line at UGE1 (FEB Gate-1) at the U-upstream end of the U-Line. That penetration is dominated by a g-2 source term and is reported in AGS Safety documentation.???? The results for the Collider ventilation shafts are shown in Table 4-G-1. The values reported in the Table are shown for the dose equivalent at the beam surface and for the vent fan cover at three feet above the berm. Many of the vent fans extend higher than three feet but, for the purpose of access control, no additional credit was taken. The labyrinths in the Transfer Line were analyzed assuming a fault with an AGS injection loss (4.8×10^{12} 28 GeV protons), and the Collider labyrinths used a DBA fault (1.14×10^{13} 250

²⁶ A. J. Stevens, C-AD/ES&F Technical Note No. 156, Summary of Fault Study Results at RHIC, July 12, 2000.

²⁷ P. J. Gollon, AD/RHIC/RD-76, Shielding at Multi-Leg Penetrations into the RHIC Collider, October 1994.

²⁸ P. J. Gollon, AD/RHIC/RD-76A, Amendment to Shielding at Multi-Leg Penetrations into the RHIC Collider, July 1996.

²⁹ A. J. Stevens, Scaling Gollon's Duct and Labyrinth Calculations, October 26, 1997.

³⁰ A. J. Stevens, Dose at Exit of Duct Covers, October 28, 1998.

GeV protons). Those archetypes that exceed the Design Criteria are appropriately controlled to exclude occupancy on top of the shaft cover.

TABLE 4-G-1

Emergency Ventilation Ducts (need 1/2XXXX)

Case	Dose at		At the		Distance to	Exit of		Fan	Figure	Berm	Cover
	Archetype	Description	Comment	Dia.	Beam Pipe	Vertical	Source				
	Length	Angle									
	(in)	(ft)	(ft)	(deg)	(mrem/fault)						
A	Sextant 3	Concrete	42	9.5	25.0	0	4-G-1	46	27		
	Structure at Spect. Tunnel										
B-1	16 ft Plate Arch		42	7.0	15.5	0	4-G-2	486	270		
B-2	16 ft Plate Arch		48	7.0	15.5	0	4-G-2	831	475		
C	20 ft Plate Arch		48	8.5	16.5	0	4-G-3	507	298		
D-1	26 ft Plate Arch		42	8.5	18.0	0	4-G-4	215	119		
D-2	26 ft Plate Arch		48	11.5	18.0	0	4-G-4	238	136		
E	Concrete Structure at		48	8.0	16.5	0	4-G-5	555	326		

4 o'clock

F-1	Injection-Ejection at Sextant 5, 7	Near Wall	48	10.0	16.5	0	4-G-6	396	192
F-2	Injection-Ejection at Sextant 5, 7	Far Wall	48	14.3	16.5	0	4-G-6	224	132
G-1	Injection/Ejection at Wide Angle Hall	Near Wall	48	8.3	16.5	0	4-G-7	529	311
G-2	Injection/Ejection at Wide Angle Hall	Far Wall	48	10.0	16.5	0	4-G-7	396	233
H	RF Cavity Sextant 5	42	10.0	17.5	0	4-G-8	186	103	
I-1	Alcove A and C - Typical	42	15.5	10.0	15	4-G-9	516	258	
I-2	Alcove A and C - Typical	48	15.5	10.0	15	4-G-9	801	411	
J-1	Alcove B - Typical	42	16.0	13.0	50	4-G-10	81	42	
J-2	Alcove B - Typical	48	16.0	13.0	50	4-G-10	150	83	
V-2	X-Y Arcs	36	6.7	16.0	0	55*	N/A		
V-3	New Block Wall in W-Line	36	3.5	11.0	0	166*	N/A		

*AGS Class Fault

The results for the access and emergency egress labyrinths and escape hatches are shown in Table 4-G-2. There is an interlocking Chipmunk at the exit of the curved labyrinth, WGE2 at the X-Y split. Fault studies were conducted at most of the penetrations in the Transfer Line during the 1995 commissioning run. They were found to be within the predictions.

TABLE 4-G-2

Access and Emergency Egress Labyrinths (Need ½ XXXXX)

Location of Archetype	Case	Drawing	Dose
(mrem/fault)			
Injection Line Exit at AGS to RHIC Transition	P-1	S-13/42	1*
Injection Line X-Y Split	P-2	S-13/42	32.3*
Alcove B	P-3	A-5/51	7
Alcove A and C	P-4	A-4/51 and A-5/52	70

7-B Emergency Exit (Typical)	P-5	A-5/51	33
Narrow Angle Hall to Support Building	P-6	A-3/8	19
4 O'clock Support Building	P-7	A-2/7	16
Ring to Building 1005S	P-8	S-1/56	13
Injection/Ejection Structure to Building 1007 and Emergence Above Ground	P-9	A-3/5 and S-9/38	3.6, 36
10 O'clock Tunnel Exit Through the Berm	P-10	A-3	2
Ring to 10 O'clock Support Building	P-11	A-3	270
12 O'clock Tunnel Exit Through the Berm	P-12	A-12	3
Ring to 12 O'clock Support Building	P-14	A-3A	11
8 O'clock Support Building	P-15	A-4/9	21
U-Line Near Fork to Old Neutrino Line	P-16	D14-1192 A6 Rev A-1	8*
6 O'clock Support Building	P-17	A-3/15	24
Escape Shaft Near Building 1005S (Typical)	P-19		60

*AGS Class Fault

There are a number of straight-through penetrations into the beam enclosures. They are cylindrical shafts used for survey and, large rectangular shafts on either side of the 6, 8 10 and 12 o'clock halls to permit cryogenic piping to bypass the experiments. The method used to assess these voids in the shielding is shown in Appendix 19. The doses directly above these penetrations for a DBA Collider fault are:

Large Rectangular Cryogenic Piping Shaft - 6,000 mrem

12 inch diameter Cylindrical Shaft - 110 mrem*

18 inch diameter Cylindrical Shaft - 300 mrem

*For a DBA in the Transfer Line, with an injection beam from the AGS in accordance with the Beam Loss Scenario in Appendix 8, a dose of 15 mrem would result. If a person were standing beside the cylindrical shafts in the Collider instead of directly above, the dose would be at least a factor of 10 less. To exclude personnel from the vicinity of the cryogenic piping shafts they will be secured by a 6 foot fence and locked gates under the control of the Radiological Control Technician Watch. The area will be swept via procedure before operation with beam. The technical basis for the fencing around the cryogenic piping is shown in Appendix 19.

Radiation Potential From RF Cavities

The RF cavities located in the vicinity of the 4 o'clock region produce x-rays as a result of normal operation due to conditioning and multipackting. At full power, dose rates based on

measurements during engineering tests of the Proof of Principal (PoP) acceleration cavity and Storage cavity are expected to be in the range of 25-200 rad/hr at 1 foot from the cavity³¹. The power supplies for the cavities are interlocked to the PASS system, with the capability of stand-alone running when the Collider is not in operation. Sectionalizing gates inside the Collider Tunnel prohibit access to the cavities by personnel, when the adjacent tunnel is in an access permitted state to secure the cavity area for operation. Operation of the RF cavities do not cause x-ray radiation outside the Collider shielding.

4.5.5. Exposure to Induced Activity

Because the accelerator is properly designed with respect to shielding against prompt radiation and has proper access controls to prevent exposure of personnel to direct primary beam, induced radioactivity is the dominant source to occupational radiation dose.

The materials used in construction of the injectors, accelerators, collider and experimental areas are limited in number, the most important being iron, steel, copper, aluminum, concrete, oil and plastic. These metals and materials are generally not used in their pure form; that is, they have welds, or they are alloyed with other metals, or they are parts of beam-line components. Thus, irradiation produces a variety of radionuclides in any given item. Based on studies of the C-A radioactive waste stream, radionuclides ranging in half-life from days to years are formed in these materials. Table 4.5.4.b is a summary of the dominant radionuclides produced in each material. Experience with these activated materials and

³¹ S. Musolino, Measurements of Prompt Radiation from the PoP RF Cavity Test Stand in Building 1005 Highbay, August 8, 1995. S. Musolino, Measurements of Prompt Radiation from the Storage RF Cavity Test 4 o'clock Service Building, August 8, 1995.

radioactive waste streams at BNL accelerators and experiments, shows that the current administrative and work controls are adequate to minimize their hazards.

Table 4.5.4.b Radionuclides Predominantly Observed in the Waste Stream from High Energy Hadron Accelerator Operations

Irradiated Material	Radionuclides Observed in the Waste Stream
Plastic, Oil	^7Be , ^{22}Na , ^{46}Sc , ^{54}Mn , ^{57}Co , ^{60}Co , ^{68}Ga , ^{88}Zr , ^{113}Sn , ^{124}Sb , ^{125}Sb , ^{133}Ba , ^{134}Cs , ^{207}Bi
Concrete	^7Be , ^{22}Na , ^{46}Sc , ^{54}Mn , ^{57}Co , ^{58}Co , ^{60}Co , ^{65}Zn , ^{110}Ag , ^{134}Cs
Aluminum	^7Be , ^{22}Na , ^{54}Mn , ^{57}Co , ^{58}Co , ^{60}Co , ^{65}Zn , ^{68}Ga , ^{95}Nb , ^{110}Ag , ^{133}Ba , ^{134}Cs
Iron, Steel	^7Be , ^{22}Na , ^{46}Sc , ^{54}Mn , ^{59}Fe , ^{56}Co , ^{57}Co , ^{60}Co , ^{65}Zn , ^{68}Ga , ^{75}Se , ^{95}Nb , ^{110}Ag , ^{113}Sn , ^{124}Sb , ^{125}Sb , ^{133}Ba , ^{134}Cs , ^{207}Bi
Copper	^7Be , ^{22}Na , ^{54}Mn , ^{57}Co , ^{58}Co , ^{60}Co , ^{65}Zn , ^{68}Ga , ^{110}Ag , ^{133}Ba , ^{134}Cs

Radioactivity is also produced directly in the primary cooling water systems. Experience indicates that ^7Be and ^3H are the two long-lived radionuclides that are produced. Depending upon the operating schedule, estimates indicate on the order of a hundred mCi of these longer-lived radionuclides will be produced annually. Operation of AGS primary cooling water systems causes much higher activities and volumes of activated cooling water. Handling AGS cooling water and responding to spills has shown that there is no significant hazard to workers. Current procedures and controls will assure that any machine or experiment primary cooling water will not be hazardous to workers. Tritium is always produced in conjunction with gamma emitters so a gamma detector is sufficient to monitor spilled primary water. In the event of an inadvertent release or spill, gamma radiation monitors in the sanitary waste system, the system which receives spilled activated cooling water, are designed to trigger the diversion of significant levels of radioactive water away from the BNL Sewage Treatment Plant and toward a lined hold-up pond for additional sampling and treatment.

In addition to direct activation of primary water, slight amounts of radioactivity that is induced in the magnets is picked up in this same cooling water due to corrosion. Current AGS systems have μCi amounts of corrosion products such as ^{54}Mn , ^{22}Na and ^{65}Zn . On the other hand, activated cooling water is in closed re-circulated systems that are de-ionized, which greatly reduces the amount of dissolved corrosion products. Closed system or "contact" cooling water is monitored before discharge. The planned release of cooling water follows receipt of analytical data showing acceptable levels for all radionuclides as long as the requirements of the State Pollution Discharge Elimination System Permit (SPDES) are satisfied. Additionally, the metals content is monitored in both "contact" and "secondary" cooling waters.

Primary cooling water will briefly contain small amounts of short-lived radio-gases that are isotopes of nitrogen and oxygen. The minor external radiation hazard near the contact cooling water piping from circulating these radio-gases is momentary, lasting 5 to 10 minutes after shutdown of the beam. The most radioactivity in cooling water, other than dissolved short-lived radio-gases, is from tritium. The current level of tritium in the Booster magnet cooling water, which has been building up for several years, is 2.8×10^5 pCi/L, which is about 14 times greater than the Drinking Water Standard. The annual Booster accelerated particles averaged over the last few years is about 2.0×10^{20} GeV. Thus by ratio to annual running, 1.0×10^{17} GeV, the tritium in cooling water would build up by about 150 pCi/L per year. This level would be at or below the minimum detectable level for routine tritium monitoring, at least during the first few years, and cooling water leaks would not be of concern with regard to spreading radioactive contamination. Other radionuclides in cooling water will be either too short-lived (minutes) or be removed by the ion-exchange system and trapped in solid media.

Secondary water from the cooling towers, which is not radioactive, is discharged into recharge basins if the metals content is not greater than permitted.

Regarding hazards from activated animal waste; assume a sample receives a near lethal dose of 500 rad (5 Gy) from 1 GeV/nucleon iron ions. This corresponds to 4×10^8 iron-ions for a 20 cm^2 beam-size, or 2.3×10^{10} nucleons at 1 GeV. See C-A OPM 9.1.11, Section 5.4, for dose to beam conversion functions. For soft tissues, water comprises about 80% of mass. Assume a sample is made of water, presents a 20 cm^2 area to the beam and is 20 cm long. Given a 30 mb cross-section for tritium production from high-energy nucleon-collisions with oxygen, the total tritium created in a sample from a 500 rad dose is 22 pCi. Given that water has about 200 to 400 pCi/L of naturally occurring tritium, the activated excreta of animals is not expected to be measurable nor is it a significant radioactive hazard.

4.5.6. Fire Hazards

The primary combustible loading in the injectors, accelerators, collider and experiments consists of magnets, power and control cables, and beam diagnostic equipment located throughout the complex. None of the materials is highly flammable, and with the possible exception of small amounts of control cable, all are expected to self-extinguish upon the de-energizing of electric power. XXXSmall amounts of flammable materials, in quantities of less than 1 quart each, will be used in the Support Building. The buildings, tunnel and cooling towers are all constructed of non-combustible materials.

Due to a system for diversion of radioactive liquid effluent to a hold-up pond, there are no environmental impacts due to release of contaminated water from the fire protection water

system. Water sprayed on radioactive equipment may become slightly contaminated but would enter the sanitary system and be monitored before release. There are no significant amounts of combustible activated materials in the tunnel or beam lines and no significant radioactive particles would be present in smoke. Thus, there is no significant environmental hazard from a fire at the Booster Applications Facility.

The danger of an over-pressure associated with a detonation of hydrogen from such a target is about 17 lbs of TNT equivalent. The over-pressure wave is such that it will be lethal to anyone out to a 30-foot radius. There is no full-time occupancy within this zone and equipment racks and monitoring stations are typically more than 30 feet away. These zones are maintained as low-occupancy areas. Experimenters and watch personnel may walk by or briefly work in the zone; typically, one or two people at a time. Flying debris will pose an additional threat. The peak over-pressures are likely to be significant to move large magnets nearby, collapse the target enclosure and collapse nearby experimental detectors. The nearby secondary beam dumps will likely remain standing.

4.5.7. Hazard Controls

The purpose of this section is to briefly summarize the various system features and administrative programs that help to control hazards or the minimize risk of various hazards.

Radiation Protection

The significant hazard at the Booster Applications Facility is ionizing radiation, and operations are planned to be within DOE dose guidelines. The Department uses a graduated system of shields, fences or barriers, locked gates, interlocks and procedures to match access restrictions with potential radiation hazards that satisfies both the BNL and DOE requirements.

Although the Laboratory site is a limited access site, service personnel from off-site or BNL non-radiation workers may work near the accelerators or may traverse the complex. The Laboratory policy is to restrict the dose to 25 mrem per year to such personnel. The C-A Department adheres to this policy by using shielding and radiation monitoring devices that prevent radiation levels from exceeding set points.

Shielding for Booster Applications Facility is also designed to permit access by appropriately trained personnel to areas adjacent to the beam enclosures and Target Room even with nominal inadvertent beam loss. In locations where the losses are expected to be greater, such as outside the shielding near collimators or the beam stop, physical barriers such as fences are used to control access and minimize exposures. Depending on the area classification, these barriers may be locked and/or posted as Controlled Area or Radiation Area.

There is the potential of significant residual activity in several locations, which are collimators, injection region, and beam dump. To work near these locations, movable shielding may be brought into place using the remote capabilities such as a crane or a fork truck. This minimizes the potential integrated person-dose for work done within the beam enclosure.

Permanent Shielding and ALARA Dose

Shielding design analyses were performed for all sections of the Booster Applications Facility, and ALARA was integrated into the overall facility design. Soon after beam is available, studies will be conducted in order to verify the design and to optimize shielding, as needed, to help achieve an ALARA dose to facility personnel and facility users. Extensive radiation surveys of normal operations, as well as low-intensity simulated, credible beam faults, will be conducted during commissioning and initial operations. These surveys will provide assurance and verification of the adequacy of the shielding and access controls. It is noted that the permanent shielding and access controls are configured to support the BNL RadCon Manual dose limit requirements, and are further enhanced to support the BNL RadCon Manual ALARA considerations.

The shield was planned with ALARA in mind such that, during normal operations, the dose rate on accessible outside surfaces of the shield is planned to be less than 0.25 mrem/h in areas under access control. Areas under access control at the Booster Applications Facility are all designated Controlled Areas or radiological areas as defined in the BNL RadCon Manual. The design of 0.25 mrem/hr is a guideline based on the actual ALARA design objective of less than 500 mrem per year. That is, assuming 100% occupancy at the shield face, a 2000-hour per year residence time yields an acceptable ALARA design objective of 500 mrem. The 500 mrem per year ALARA design objective is one half the design objective stated in 10CFR835 § 835.1002 (b).

Since there are many ways to control access and residence time by area designation, training, signage and work planning and since there is a decrease of dose rate with distance from the shield face, significantly higher shield face dose rates are often acceptable. Therefore, in the following subsections, the shields are evaluated in terms of the guideline of 0.25 mrem/h, and

instances where higher values may be acceptable are mentioned to indicate where area designations will play a major role in minimizing radiation exposures.

Permanent Shielding Materials

The permanent bulk shielding materials for the Booster Applications Facility are primarily materials used at existing BNL accelerator facilities. For example, concrete, iron and earth provide protection for personnel outside the Booster Applications Facility tunnel and Target Room. In addition, as discussed later in this analysis, the transport line and the beam dump berms are covered with caps to prevent leaching of soil activation products, tritium and sodium-22, from contaminating the groundwater. In addition to the materials mentioned above, paraffin, borated paraffin, polyethylene, borated polyethylene and lead may be used for local shielding and in special circumstances. Shielding configuration is closely controlled and may not be changed without review and approval of the C-A Radiation Safety Committee (RSC).

Radiation Detection and Radiation Interlocks

At locations external and/or adjacent to beam enclosures where unlikely but possible beam loss may occur, the use of hard-wired, fail-safe interlocking radiation monitors is planned. This technique is standard practice at DOE accelerator facilities to maintain radiological-area classification compliance by providing a robust and rapid beam inhibit if any monitor exceeds a preset interlock limit. The Booster Applications Facility will treat these radiation monitors as part of the QA level A1 safety-significant access-control-system for personnel protection.

Interlocking radiation monitors are to be calibrated annually. These radiation monitors have been dubbed ‘Chipmunks.’ They are tissue-equivalent ionization chambers that measure dose equivalent rate, in mrem per hour, from pulsed, mixed-field neutron and gamma radiation. Chipmunks are used as area-radiation monitors for personnel protection and are located throughout the facility in accessible areas. Chipmunks are used to interlock the accelerator beams should radiation levels exceed limits defined by the C-A Radiation Safety Committee. The operation of Chipmunks with interlocking capability is fail-safe. Loss of power results in beam off for interlocked Chipmunks, and/or an alarm in the Main Control Room in Building 911, a control room that is manned around-the-clock during operations. Additionally, the Chipmunk uses a built-in keep-alive radiation source to monitor for failures. Such a failure will trigger an alarm in the Main Control Room and/or an interlock when appropriate.

The interlock system is hard-wired and uses relay logic and PLCs to activate or deactivate a device such as a beam stop or magnet power supply to prevent beam from entering the fault area when a fault condition is detected. The portion of the system that is PLC based is patterned after the system used at RHIC. This system is monitored by an independent computer, and the fault condition is logged.

Fixed-location area-radiation monitors such as Chipmunks also provide real-time dose information at various locations along the beam path and in the target and support buildings. This dose rate data is logged every few minutes and stored on computers. General locations have been selected for the real-time monitors; exact locations will be determined based on beam-loss tests conducted during the commissioning phase and on subsequent radiation surveys during operation. Final area radiation monitoring instrument locations will be approved by the Radiation Safety Committee.

Additional area monitors may be used to assess the long-term integrated dose in areas accessible to the public and other individuals not wearing personnel dosimeters. Thermoluminescent dosimeters (TLDs) identical to those worn by radiation workers will be mounted in locations approved by the Radiation Safety Committee for this purpose. The dose recorded by these TLDs will be indicative of the exposure of a person spending full time at that location. Neutron dosimeters, if their use is indicated for this purpose, will be attached to phantoms to simulate use by personnel.

Portable Radiation Monitors

Portable radiation detection instruments will be used by Radiological Control Technicians (RCTs) and, potentially, other trained and approved C-A personnel, to measure the radiation fields in occupied areas during commissioning and periodically during normal operations. These measurements will be used to establish and confirm area radiological postings. Instruments used for this purpose will be appropriate for the type and energy of the expected radiation, and will be calibrated in accordance with requirements.

Frisking Instruments

Experience at the AGS with virtually identical beams and identical NASA experiments have shown that contamination is not expected at Booster Applications Facility. However, routine contamination surveys will be conducted to verify that contamination is not a problem.

Instruments used to frisk personnel who are exiting posted areas that might contain removable contamination will be used as appropriate.

Personnel Dosimetry

All radiation workers will wear appropriate TLDs and self-reading dosimeters as required by the BNL Radiation Control Manual while working in areas posted for radiation hazards. Dosimeters will be exchanged on a regular basis and processed by a DOE LAP-accredited laboratory. Records of the doses recorded by these dosimeters will be retained, and these records will be made available to the monitored individuals.

Access Controls Systems

The radiation security system will use the same design as existing access controls at C-A facilities that have been in operation for nearly 40 years. The C-A Department has classified the security system as QA level A1 according to the C-A QA plan, but the Department allows certain components to have a lower classification because failure is to a safe state or critical parts are redundant. The Access Controls Group installs industrial grade components only. This Group labels parts that pass incoming tests as A1 or A2 and places labeled parts in controlled storage areas. The Group maintains documentation for these acceptance tests.

The basic design principles of the access control system are:

- Either the beam is disabled or the related security area is secured.

- Only wires, switches, relays, PLCs and active fail-safe devices, such as Chipmunks, are used in the critical circuits of the system.
- The de-energized state of the relay is the interlock status; that is, the system is fail-safe.
- Areas where radiation levels can be greater than 50 rem/h require redundancy in disabling the beam and in securing the radiation area.
- If a beam fails to be disabled as required by the state of its related security area, then the upstream beam would be disabled; that is, the system has backup or reach-back.

Very High Radiation Areas are those areas that enclose primary beam such as the Booster Applications Facility beam line and Target Room. Very High Radiation Area hardware requirements comply with the BNL RadCon Manual. The C-A Radiation Safety Committee requires: 1) locked gates with two independent interlock systems, 2) fail safe and redundant radiation monitors or other sensing devices, 3) indicators of status at the facility in the Main Control Room, 4) warning of status change, and 5) emergency stop devices within potential Very High Radiation Areas.

The C-A Radiation Safety Committee reviews interlock systems for compliance with requirements in the BNL RadCon Manual, Standards Based Management System requirements and C-A Operations Procedure Manual procedures. A Representative of the BNL Radiological Controls Division is a member of the C-A Radiation Safety Committee. The C-A Radiation Safety Committee defines the design objectives of the security system and approves the logic diagrams for relay-based circuits and state tables for PLC-based circuits. Cognizant engineers sign-off on wiring diagrams and the C-A Chief Electrical Engineer approves each diagram. The C-A Access Controls Group maintains design documentation.

The Access Controls Group conducts a complete functional check of all security system components at an interval required by the BNL Radiological Control Manual. In the checkout, the Access Controls Group checks the status of each door-switch on a gate, and each crash switch in the circuit. They check the interlocks and the off conditions for all security-related power-supplies to magnets, magnets that may act as beam switches, and for all security-related beam-stops. They check every component in a security circuit. As they test, they fill-out, initial and date the security system test-sheets obtained from the C-A Operations Procedure Manual. Test records are maintained as required by the C-A Operations Procedure Manual.

Electrical Safety

The requirements for electrical safety are given in detail in the BNL Standards Based Management System and the C-A Operations Procedures Manual. Electrical bus work is covered to reduce/prevent electrical hazards in the power supply areas. In beam enclosure areas, exposed conductors will not be present and magnet buss will be covered. The Main Control Room will lock out all power supplies that power devices inside a beam enclosure whenever the area is placed in Restricted Access mode. In Controlled Access mode, even though the magnets will not be powered, the power supplies will not be locked out. Workers are trained to assume that magnets are powered in all cases and to treat them accordingly. In cases where workers are required to work on or near a specific magnet during Controlled Access or Restricted Access, the magnet power supply will be locked out and tagged out by the worker.

In some cases, it will be necessary to work near magnetic elements while powered. Appropriate control over access during this mode is maintained by the Operations Coordinator.

Work planning, Working Hot Permits and training requirements for entrants under these circumstances address concerns for inadvertent contact with powered conductors and exposure to magnetic fields.

Lockout/Tagout

Lockout/tagout procedures are specified in the C-A Operations Procedure Manual. All workers will be required to train in lockout/tagout procedures at a level consistent with their position. Where electrical hazards could be present to C-A personnel working in an area, lockout/tagout procedures shall be executed only by trained and authorized personnel.

Safety Reviews and Committees

Standing safety committees shall be utilized throughout design, construction, commissioning and operation to focus expertise on safety, environmental protection, pollution prevention and to help maintain configuration control. See Chapter 3, Section 3.4.3.10.

Training

Worker training and qualification is an important part of the overall ESH plan for C-A Department. Training and qualification of workers is described in the Operations Procedures Manual and the required training for individuals is defined in the Brookhaven Training Management System (BTMS). All Booster Applications Facility personnel and experimenters

will require an appropriate level of training to ensure their familiarity with possible hazards and emergency conditions.

Workers will be trained in radiation and conventional safety procedures at a level consistent with their positions. The number and type of training sessions/modules will be assigned using a graded approach commensurate with the staff members responsibilities, work areas, level of access, etc. An up-to-date record of worker training will be kept in the BTMS database. Radiation worker access will only be allowed if adequate training is documented, except in cases of emergency. Training procedures and course documentation will be reviewed and updated periodically.

Personal Protective Equipment

Special clothing will be used to protect workers who are exposed to the various hazardous materials found at the Booster Applications Facility, including chemicals and radiation. The clothing for a particular application will be selected considering the expected hazards; a variety of types of clothing will likely be needed to meet all hazards. There are no predicted hazards that are unique to the Booster Applications Facility, and experience gained at other C-A facilities will be applied to ensure the adequacy of protective clothing in a particular application.

Respiratory protection will be provided for workers who might otherwise be exposed to unacceptable levels of airborne hazardous materials, including chemicals and radioactive materials. Respiratory protection will be selected, used and maintained per OSHA 29CFR1910.134 and BNL Respiratory Protection Procedures.

Control of Radiation and Radioactive Materials

Control of Direct Radiation

Shielding will be used to reduce radiation levels in occupied areas to acceptable levels. The C-A Department's shielding policy is given in [Appendix 10](#). Potential access points into areas where personnel are prohibited during operations will be controlled by the Access Control System. Areas with elevated radiation levels that are accessible to personnel will be posted in accordance with BNL RadCon Manual requirements, and individuals will be appropriately trained before being granted unescorted access to Controlled or radiological areas.

Individuals entering areas posted for direct radiation will have appropriate dosimetry and will have written authorization to enter into and perform work in radiological areas. Periodic radiological surveys during operations will confirm that postings are appropriate. Exposure of personnel to radiation will be controlled through the combination of exclusion from areas with immediately hazardous radiation levels and postings that inform workers of hazards in accessible areas.

Control of Radioactive Materials and Sources

When the beam is turned off, the remaining radiation hazard comes from activated material and sources. Activated material may be a direct radiation hazard, and may have removable contamination. All known or potentially activated items will be treated as radioactive

material and handled in accordance with BNL RadCon Manual requirements. Unlabeled radioactive material that is accessible to personnel will be in an appropriately posted radiological area. Suspect radioactive material will be surveyed by a qualified person before release and then controlled in accordance with the survey results. Process knowledge may also be used to certify items being removed from radiological areas as being free of radioactivity. Known radioactive materials will be appropriately labeled before removal from an area that is posted and controlled. Radioactive items with removable contamination on accessible surfaces will be packaged before removal from posted radiological areas. Workers whose job assignment involves working with radioactive materials will receive documented training as radiological workers. Radioactive sources below accountable-activity-limits will be treated as radioactive material. Accountable sealed radioactive sources will be controlled, labeled and handled in accordance with the BNL RadCon Manual and the C-A Operations Procedure Manual. Accountable sealed radioactive sources that are in regular use will be inventoried and leak-tested every six months.

Control and Use of Hazardous Materials

The BNL Chemical Management System is designed to ensure that workers are informed about the chemical hazards in their workplace. The Chemical Management System is maintained to comply with OSHA and EPA regulations concerning hazardous chemical communications. This program includes provisions for policy, training, monitoring exposure limits, handling, storing, labeling and equipment design, as they apply to hazardous materials. Inclusive in the hazardous material protection program will be: procurement, usage, storing, inventory, access to the hazardous materials, as well as housekeeping and chemical hygiene

inspections of the Booster Applications Facility Experimental Support Building. All BNL general employees receive appropriate general Hazard Communication training. Standards for general hazardous materials communication and for special materials, such as beryllium, mercury and biological materials are specified by the BNL Standards Based Management System. Training to these standards is provided, and the training program records are maintained on the BNL BTMS. Booster Applications Facility employees working in areas with a potential for exposure to hazardous chemicals receive appropriate job-specific training at the time of initial assignment and whenever a new hazard is introduced into the work area. A comprehensive listing of all Materials Safety Data Sheets for the chemicals used at the Booster Applications Facility site is available on the BNL web or equivalent. The system of work controls, which is part of the BNL Integrated Safety Management System, requires enhanced work planning for work with certain hazardous materials; for example, beryllium. The enhanced work planning will assure that adequate hazard controls and completion of required training are in place before work with hazardous materials can begin.

The use of flammable liquids will be minimal. The anticipated use is less than 1 quart in each laboratory space as a solvent. Any use of flammable liquids follows BNL ES&H Standards / SBMS requirements. Propane for Bunsen burners is either stored external to the Support Laboratory building or contained within a continuously vented cabinet, which discharges to the outside.

4.5.8. Significant Environmental Aspects and Impacts

In support of Brookhaven National Laboratory's broad mission of providing excellent science and advanced technology in a safe, environmentally responsible manner, the Collider-Accelerator Department is committed to excellence in environmental responsibility and safety in all C-A Department operations.

To provide excellent science and advanced technology in a safe and environmentally responsible manner the Collider-Accelerator has, over the past decade, continuously reviewed the aspects of its operations in an effort to identify and accomplish waste minimization and pollution prevention opportunities. This process began in 1988 with the development of formal environmental design guides and a design review process. More recently, this effort has resulted in a further formalization of its processes under the guidelines of ISO 14001, the BNL ISO 14001 "Plus" Environmental Management System Manual, and SBMS subject areas governing ISO 14001 implementation. Based on the aspect identification and analysis process in the Subject Area, Identification of Significant Environmental Aspects and Impacts, the following aspects are significant to the Booster Applications Facility activities:

Regulated Industrial Waste

Hazardous Waste

Radioactive Waste

Atmospheric Discharge

Liquid Effluents

Storage/Use Of Chemicals or Radioactive Material

Soil Activation

Water Consumption

Power Consumption

The environmental policy as set forth by Brookhaven National Laboratory in the Environmental Stewardship Policy is the foundation on which the C-A Department manages significant environmental aspects and impacts. The formal management program is called the C-A Environmental Management System. The Environmental Management System consists of the following elements, the details of which may be found in the [C-A Operations Procedure Manual](#).³²

Environmental Policy

Planning

Environmental Aspects and Impacts

System for Determining Legal and Other Requirements

System for Defining Objectives and Targets

Environmental Management Programs

Implementation and Operation

Structure and Responsibility

Training, Awareness, and Competence

Communication

Environmental Management System Documentation

Document Control

Operational Control

Emergency Preparedness and Response

Checking and Corrective Action

Monitoring and Measurement

³² <http://www.rhichome.bnl.gov/AGS/Accel/SND/OPM/Ch01/01-10-02.PDF> Environmental Management Program Description

Nonconformance and Corrective and Preventive Action

Records Management

Environmental Management System Audit

Management Review

The requirement for a process evaluation is listed in C-A OPM Chapter 13. Waste streams will be reviewed by the ECR and a process evaluation denoting all material inputs and outputs for the will be performed before commissioning the facility for operations.

4.5.9. Hazard Reduction Associated With Waste Generation and Handling

Hazards associated with handling, packaging, treating and disposing of wastes generated during operation and modification of the facility are reduced when the generation of these wastes is minimized via pollution prevention (P2) techniques. The BNL approach to P2 associated with the operation and modification of Booster Applications Facility is to address it during the design and construction phase. The objective is to minimize or eliminate the anticipated costs associated with hazardous and mixed waste generation as well as the treatment and disposal of wastes and the consumption of resources in all life cycle phases: construction, operation, closure and decommissioning. Dollars spent during the design phases will provide for significantly reduced total costs over the life of the facility thus making more funds available for science. The following are the main objectives of the BNL P2 program:

Minimize the amount of hazardous, radioactive and mixed wastes that are generated.

Minimize the cost of waste management.

Comply with federal, state and local laws, executive orders and DOE orders.

The Collider-Accelerator Department has implemented a P2 program as part of its commitment to comply with the Environmental Management System and ISO 14001. C-A facilities are registered to the ISO standard by a third party registrar. A number of lessons learned from other BNL operations are incorporated into C-A operations. Modifications to C-A operations have helped minimize hazards and costs associated with the generation of waste streams.

4.5.10. Fire Detection, Egress, Suppression and Response

In general the basis of design for fire detection, egress, suppression and response have been determined in the fire hazard analysis (FHA) in [Appendix 8](#). The Booster Applications Facility complies with DOE fire protection guidelines as well as NFPA's. The system is integrated with the site-wide system and is comprised of an automatic fire detection and suppression system that includes automatic wet-pipe fire suppression and rapid response capability coverage by the BNL Fire Department. Sprinklers are provided at the building ceiling or roof levels, intermediate levels and at or within enclosures, as required. Because of the low flammability of the magnets, power and control cables and beam diagnostic equipment in the tunnel, the tunnel does not have an automatic fire suppression system. The tunnel has a fire standpipe. Manual and automatic fire detection and alarm initiation devices are installed throughout the facility. Where needed, smoke and/or heat detection devices are supplemented with pressure sensitive sensors, combustible gas detectors or other advance detection devices. The appropriate portable fire extinguishers are provided for manual fire fighting efforts. Booster Applications Facility fire alarms are alarmed at the BNL Fire Department (Building 599), which

is continuously manned and will respond to every fire alarm. This will put additional professional fire fighting resources into action within a short period. Roadway around the facility helps protect it from surrounding wildfires. The building roofs are non-combustible metal and do not ignite from burning ash from brush fires.

The tunnel is joined to the Booster tunnel via a penetration that allows for transport of the beam in a vacuum tube to the tunnel. This transfer line lacks combustibles and cannot convey a fire from tunnel to the other. While not a firewall, this arrangement provides a physical barrier that isolates the Booster and .

The means of egress for occupancies is in accordance with NFPA 101. A tunnel exhaust fan (nominal 17,000 cfm) is located at the tunnel midpoint for rapid smoke removal. The fan is not required by code but can be manually started while fighting a fire in the windowless tunnel.

4.5.11. Routine Credible Failures

Routine credible challenges to controls associated with worker and experimenter protection and with environmental protection are further detailed in [Appendix 9](#).

Beam losses in the Booster Applications Facility enclosures are sufficiently attenuated by the bulk shielding for expected routine operation. Adequate shielding is provided to meet requirements established by the Laboratory for permissible exposure to radiation workers and to members of the public during normal machine operations. Present shielding designs reduce all normal radiation levels to well below the DOE ALARA guidelines.

Exposure to nearby facilities is less than 25 mrem per year and much less than 5 mrem per year at the site boundary, which are the Laboratory guidelines for radiation exposure for

nearby facilities and the site boundary, respectively. Radiation exposure to maintenance workers is reduced through the design of equipment to simplify maintenance and the selection of materials to minimize failures. In particular, equipment at high loss points such as targets receive detailed examination to assure that radiation exposure received in passing and during the maintenance of these components is kept as low as reasonably achievable. Through such reviews, it is reasonable to expect that maintenance activities be controlled to maintain radiation exposures well within the DOE annual limits, limits that are 5 to 20 times higher than the ALARA guidelines.

There are no gaseous, liquid or dispersible quantities of radioactive materials, except for the radioactivity induced in magnet cooling water. In primary beam-line areas where the cooling water might escape confinement, e.g., a hose break, water detection mats underneath the magnets alarm and alert the watch personnel. Watch personnel are trained to confine, clean up and report water spills to management. Experience indicates that up to several hundred gallons may leak onto the concrete floor. Spilled water is sampled before release to the appropriate waste stream. No off-site threats to the public are anticipated.

4.5.12. Maximum Credible Accidents

This section describes the bounding analysis scenarios for credible Booster Applications Facility accidents.

Maximum Credible Beam Fault

Not all protons will be stopped at the targets or at well-defined loss points; some may be lost during transport. The design goal of no more than 20 mrem per full-fault event is adhered to in the design of shielding and radiation monitoring systems. Typically, the shielding on the transport lines allow these areas to be designated no more than a "High Radiation Area" during a full-fault event; that is, maximum hourly dose rate during a fault is less than 5000 mrem in 1 hour. These areas are further protected by radiation monitors, which are part of the access control system (ACS) that turns off the radiation source within 9 seconds of detecting a fault condition. Thus, the design guideline of no more than 20 mrem per event is met through a combination of shielding, radiation monitors and beam interlocks.

It is noted that placement of an array of chipmunk radiation monitors to catch a random fault anywhere along the beam line is not the intended strategy. Arbitrary losses will likely be detected, at least at some level, by one of three active chipmunks mentioned in Section 3.2.3. Experience at C-A shows that use of 1) thick shielding along the beam line and at the Target Room, 2) fences and barriers at the berm, 3) ALARA tuning procedures, 4) radiation alarms in MCR and procedures that call for response to radiation alarms are sufficient to protect personnel in locations not directly monitored by chipmunks.

A defocused or mis-steered beam during full intensity operation can cause a significant local loss of beam on a magnet. The worst-case beam loss event would be in the tunnel where the shield consists of 15 feet of earth compared to the 4 feet of concrete and 11 feet of earth at the Target Room. Using the Tesch method, a point fault of high-intensity protons in the tunnel would result in a dose of about 7 mrem at the shield surface. From [Appendix 3](#), the maximum, single event, non-routine point loss was taken to be 1.5×10^{14} 3-GeV nucleons per second for 9 seconds on a magnet. The magnet represents an addition of 1 foot of iron shielding to the 15 feet

of earth. Nine seconds is the assumed response time of the ACS to interlock the beam and stop the fault.

We note that there are interlocks that would prevent high-intensity beam from entering Booster if the critical devices are satisfied for protons; that is, a low-intensity mode for the Linac is required in order for to have proton beam. Thus, the full-intensity proton beam-fault event is highly improbable. It is further noted that high-intensity protons may be allowed in Booster when critical devices are satisfied for heavy-ion running if significant proton beam cannot be transferred by extraction equipment operating in the heavy-ion mode. C-A RSC will review and approve the methods used to limit beam and determine if there are sufficient limits on the amount of beam that can be extracted.

Based on archival operating records, beam faults occur when magnet power supplies fail, or when beam-line components are misaligned and placed into the beam path. Operators in the Main Control Room detect the problem immediately due to alarms and due to the resultant interlock that turns the beam off. Operators are trained to investigate these events according to written procedures, correct the problem if appropriate, record the event for management review, and to discontinue operations if appropriate. Given the duration of these events, a few seconds or less, and the frequency of these events, several times during an annual running period, off-site radiation impact is much less than that from normal operations.

Due to the action of interlocking Chipmunks, the short-term duration of this fault causes insignificant impact either on the dose to personnel near the facility or the skyshine dose to nearby facilities or on soil activation. Part of the Booster Applications Facility commissioning process will require beam fault studies at low intensity to verify the adequacy of the shield.

Based on the system for formal design review by C-A Committees, formal training programs, formal operations procedures, formal quality assurance programs for equipment, and the extensive use of shielding and access controls, the probability of a "catastrophic" radiation exposure is extremely improbable; that is, the probability for this consequence cannot be distinguished from zero.

Maximum Credible Fire

The objectives of presenting no threats to the public health and welfare or undue hazards to life from fire are satisfied. The Booster Applications Facility complies with the "Life Safety Code" (NFPA 101) and with the specific requirements of the Occupational Safety and Health Standards (CFR29, Part 1910) applicable to exits and fire protection.

Welding gases and flammable/explosive gases used in experiments are used and stored according to NFPA codes and standards applicable to experimental installations. Gases are stored in compressed gas cylinders that meet DOT specifications. Large quantities of gas are forbidden in experimental areas, and experimenters are limited to using 100 to 200 lb cylinders during running periods. No off-site threats to the public are expected should a cylinder fail.

Experiments are designed with an "improved risk" level of fire protection. The design requirements that were used are found in: 1) DOE Order 420.1, Facility Safety and 2) DOE Order 6430.1A, General Design Criteria. Experiments are fitted with fire detectors and fire protection systems where appropriate. Fires at experiments are expected to be extinguished by these protective systems. Combustible loading of the Booster Applications Facility primary beam line consists of magnets, power cables, control cables and beam diagnostic equipment.

None of the materials are highly flammable, and with the possible exception of small amounts of control cable, all are expected to self extinguish upon de-energizing of electric power. Induced radioactivity is deeply entrapped in magnets and concrete shielding and is not dispersible in a fire. No off-site threats to the public are expected from a fire.

The personnel risks associated with the fire hazard are acceptable considering the type of building construction, the available exits, the fire detection systems, the fire alarm systems and the relative fire-safety of the components and wiring. Emergency power and lighting is available.

Travel distances to exits in the Booster Applications Facility Support Laboratory areas do not present a problem. In structures of low or ordinary hazard and in structures used for general or special industrial occupancy, NFPA 101 permits travel distances up to 120 m to the nearest exit if the following provisions are provided in full:

Application is limited to one-story buildings only.

Interior finish is limited to Class A or B materials per NFPA definitions.

Emergency lighting is provided.

Automatic sprinklers are provided in accordance with NFPA 101.

Extinguishing system is supervised.

Smoke and heat venting by engineered means or by building configuration are provided to ensure that personnel are not overtaken by spread of fire or smoke within 1.8 m of floor level before they have time to reach exits.

DOE has established limits of \$1,000,000 for a Maximum Possible Loss and \$250,000 for a Maximum Credible Loss mandating the installation of automatic suppression systems in

locations where those limits are exceeded. The installation of sprinklers in the Booster Applications Facility Support Laboratory meets these criteria.

The Booster Applications Facility tunnel, Target Room and Power Supply Building do not have sprinklers. Since there is limited combustible loading in these areas and since the maximum fire-loss potential is less than \$1,000,000, the BNL Fire Protection Engineer determined that automatic fire suppression was not warranted ([Appendix 8](#)). The tunnel, Target Room and Power Supply Building are provided with automatic fire detection. Smoke and heat venting are in accordance with the Guide for Smoke and Heat Venting, NFPA 204. The maximum travel distance from any point within the tunnel to an exit is less than 120 m and therefore within the allowable distance. The smoke-exhaust system, emergency lighting, non-flammable construction, automatic fire-detection and low hazard fuel loading make the tunnel, Target Room and Power Supply Building acceptable.

No impairment of a vital DOE/NASA program from fire can occur because the maximum credible fire does not result in loss of use of the Booster Applications Facility for a period longer than the DOE criteria of three months. Replacement equipment exists and the time necessary for clean up and restoration is less than one month.

Maximum Credible Electrical Damage

The Booster Applications Facility electrical systems and equipment are similar to those used at C-A facilities for many years. This statement does not minimize the inherent dangers; rather, it indicates that the technical personnel are experienced on accelerator circuits and devices. Additionally, they are qualified to work on the new systems. Every engineer,

technician and electrician that is expected to work on the Booster Applications Facility equipment is adequately trained. The training includes an awareness of potential hazards and knowledge of appropriate safety procedures and emergency response plans. Training is documented and a list of authorized personnel is kept on a network electronic database (BTMS) and available to supervisors.

The C-A staff is familiar with the types of electrical hazards that relate to the accelerators and experimental areas. All reasonable safety features are installed in and on the electrical equipment. The groups that maintain, repair, test and operate the equipment have the knowledge, tools and experience to perform safely. Work planning, which includes electrical safety procedures, working hot permits and job safety analyses, is done to adhere to the safe practices mandated by OSHA and the BNL SBMS Subject Area on Electrical Safety. Continued training improves the safety margin. Thus, the potential risk for a serious electrical shock is minimized to levels currently accepted throughout the industry.

4.5.13. Risk Assessment To Workers, The Public And The Environment

Radiation Risks

The routine radiation dose to workers is well below the DOE regulatory limits of 10CFR835. The range of doses received by C-A radiation workers in CY2000 is shown in Figure 4.9.1. Experience shows average exposure of C-A radiation workers is about 30 mrem per year. The dose to average C-A radiation worker is only a small fraction of the regulatory limit, and the increase in fatal cancer risk after a lifetime of radiation work, 50 years, is

insignificant, 0.06%³³ compared to the naturally occurring fatal cancer rate of nearly 20%. The risks to the public are an extremely small fraction of worker risk; a factor of over 1,000,000 times smaller.

Worker doses, even including the maximum credible beam fault dose on a frequent basis, would not cause deterministic effects such as burns or tissue damage unless an individual were in the beam enclosure during operations. The Access Control System, which is categorized as Safety Significant, assures that such irradiations are not credible.

Ozone may be produced by ionizing radiation beams that pass through air. Ozone is an injurious gas at a relatively low concentration, a few ppm, and at a short exposure period, a few hours. Mild to moderate exposure produces upper respiratory tract and eye irritations. More severe exposures may produce significant respiratory distress with dyspnea, cyanosis and pulmonary edema.³⁴

The Target Room allows particle beams to pass through up to 20 ft of air, although the experimental plan is to minimize the air gap where possible. Air emissions from the Target Room are vented to the outside at the rate of 535 CFM. The Target Room is 4000 ft³. Thus, the mean residence time of ozone in the Target Room is 7.5 minutes after the beam is off. If ventilation is off and if the maximum possible proton current from the Booster, 16.5 micro amps³⁵, is passed inadvertently to the Target Room for one hour, then 0.0043 ppm of ozone builds up. This hypothetical maximum fault level of ozone is 4% of the Threshold Limit Value (TLV), which is 0.1 ppm. Exposure at the TLV would not produce significant health effects. For the calculation of ozone concentration, it was assumed the collision stopping power for high-

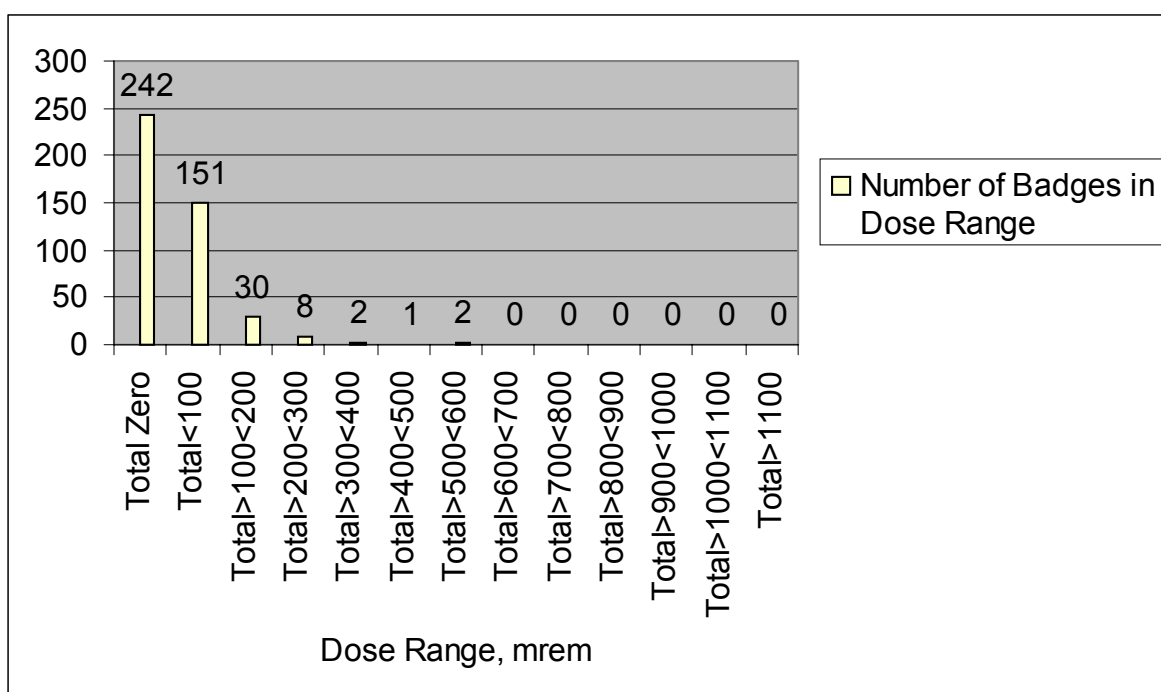
³³ This assumes a risk coefficient of 4×10^{-4} per rem for workers from NCRP Report No. 115, Risk Estimates for Radiation Protection (p. 112) and a 50-year career at 5 rem per year.

³⁴ Ellenhorn, M. J. and D. G. Barceloux, Medical Toxicology - Diagnosis and Treatment of Human Poisoning, New York, Elsevier Science Publishing Co., 1988.

³⁵ The maximum proton beam is 10^{14} protons/second, Booster Final Safety Analysis Report, 1991.

energy protons in air was 2.5 keV cm^{-1} and the equation for ozone concentration in Appendix I of NCRP 51 was applicable.^{36, 37} It is noted that the planned beam current for is about 0.02% of the maximum possible current and that ventilation is normally on. Thus, the risk of significant exposure to ozone is extremely low.

Figure 4.9.1 Range of Radiation Worker Dose at C-A Department for CY2000



Infectious Microorganism Risks

³⁶ Stopping power for protons is given in the Appendix to ICRU 28, Basic Aspects of High Energy Particle Interactions and Radiation Dosimetry, International Commission on Radiation Measurements and Units, Washington, D.C., 20014, December 1978.

³⁷ Radiation Protection Guidelines for 0.1–100 MeV Particle Accelerator Facilities, National Council on Radiation Protection and Measurements, NCRP Report 51, Washington, D.C., 20014, December 1979.

Biological safety cabinets (BSCs) are the primary means of containment developed for working safely with infectious microorganisms. This equipment, which is located in cell rooms C1 and C2 of the Support Laboratories, is appropriate when any work is done with human-derived blood, body fluids or tissues where the presence of an infectious agent may be unknown. Class II Type A BSCs provide personnel, environmental and product protection. Airflow is drawn around the operator into the front grille of the cabinet, which provides personnel protection. In addition, the downward laminar flow of HEPA-filtered air provides product protection by minimizing the chance of cross-contamination along the work surface of the cabinet. Because cabinet air exhaust is passed through a certified exhaust HEPA filter, it is contaminant-free (environmental protection), and may be re-circulated back into the laboratory (Type A), which is the type of BSC employed at cell rooms. CDC standards for BSC testing require an annual test, which includes annual efficiency tests as well as a smoke test and air velocity test. The BSC must maintain a minimum calculated or measured average inflow velocity of at least 75 linear feet per minute at the face opening of the cabinet.

Environmental Risks

The only credible risk to the environment is groundwater contamination. This may be caused by a spill of radioactive cooling water from a failed pipe or hose or by a soil cap failure, which would allow rainwater to leach the contamination into the aquifer.

An extensive groundwater-monitoring program has been instituted to verify the effectiveness of soil caps and soil-cap maintenance procedures. In accordance with DOE Order 5400.1, General Environmental Protection, groundwater quality downgradient of the

target/beam stop area will be verified by periodic sampling of two groundwater surveillance wells (e.g., existing well 054-08 and new well AGS-44). Groundwater quality will also be verified downgradient of the Booster to extraction point using two downgradient surveillance wells (e.g., existing wells 064-51 and 064-52). See Figure 4.9.3. In both areas, groundwater samples will be tested for tritium and sodium-22 to verify that the soil caps are effectively preventing rainwater infiltration of activated soil shielding. Sampling frequency for the wells will be defined in the annual BNL Environmental Monitoring Plan. The detection of unexpected levels of tritium and/or sodium-22 in groundwater will be evaluated in accordance with the BNL Groundwater Protection Contingency Plan.

There are no significant gaseous, liquid or dispersible quantities of radioactive materials, except for the radioactivity induced in magnet cooling water. Even though tritium levels in cooling water are less than the Drinking Water Standard, this water is doubly contained. In primary beam-line areas where the cooling water might escape confinement, e.g., a hose break, water detection mats underneath the magnets alarm and alert the watch personnel. Watch personnel are trained to confine, clean up and report water spills to management. Experience indicates that up to several hundred gallons may leak onto the concrete floor. Spilled water is sampled before release to the appropriate waste stream.

The operating procedures, the extensive groundwater monitoring program and the long delay times from spill to an offsite well location, which is decades, preclude the possibility of any worker or member of the public drinking radioactive groundwater.

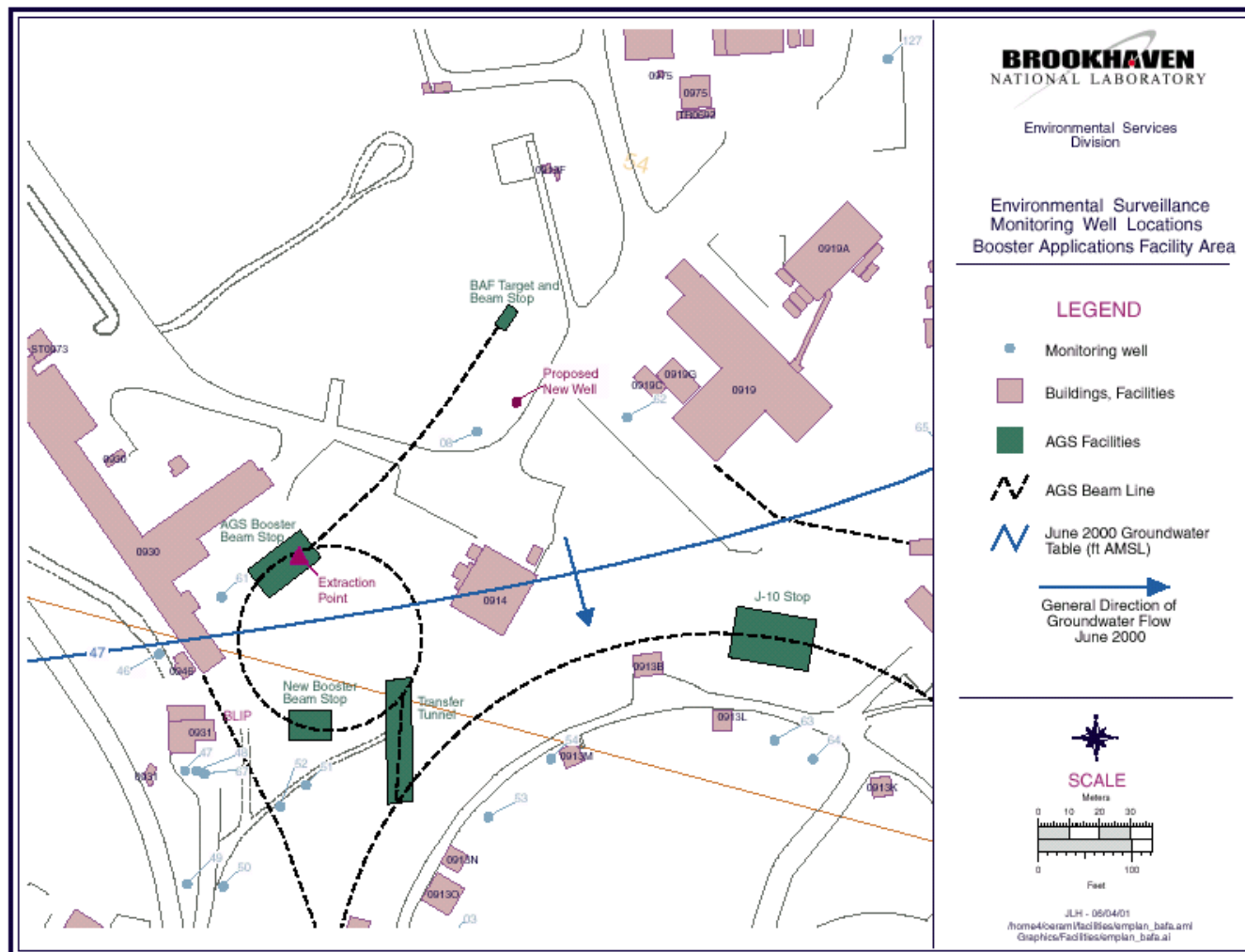
There is no credible risk to the environment from airborne releases from the animal rooms (A1 and A2) in the Support Laboratory, which are Biosafety Level 2. Ventilation is considered a secondary barrier for releases from Biosafety Level 2 facilities. Biosafety Level 2

requirements state, "There are no specific ventilation requirements. However, planning of new facilities should consider mechanical ventilation systems that provide an inward flow of air without re-circulation to spaces outside of the laboratory. If the laboratory has windows that open to the exterior, they are fitted with fly screens."

The animal laboratories have HEPA filters installed in the room exhaust and in the room re-circulation lines. The requirements for HEPA filtering of exhaust appear in Biosafety Level 3 requirements and even then are only required under certain conditions such as exhausting near occupied areas or ventilation intakes. From this point of view, HEPA testing would not be required since there is no Biosafety Level 2 requirement to have the filters installed. Although testing of HEPA exhaust is not mentioned specifically in the regulations (<http://www.cdc.gov/od/ohs/biosfty/bmbl4/bmbl4s3.htm>), a HEPA filter efficiency test is performed annually.

The room numbers, the number of hoods in the Support Laboratory, and a brief summary of the types of work done in each lab hood is maintained in a database for the laboratory. From a regulatory standpoint, ventilation and exhaust systems for laboratory operations; i.e., lab hoods, are exempt from New York State emission source permitting requirements.

Figure 4.9.3 Groundwater Monitoring Well Locations



Fire Risks

Based on the extensive use of fire protection, the appropriate location of exits and the use of an emergency exhaust system, high or medium consequence levels are extremely unlikely. Thus, the risk is acceptable.

The maximum credible fire loss in the Booster Applications Facility primary beam line would be the loss of a moderate-size magnet with adjacent beam diagnostic equipment and cabling, about a one hundred thousand-dollar property loss. In experimental and Support Building areas, the fire loss is estimated to be less than several hundred thousand dollars worth of experimental equipment. Thus, the consequence level for loss of equipment is medium. Based on the use of non-flammable materials in construction and low fuel loading, fire is not likely in the life cycle of the Booster Applications Facility and the risk is acceptable.

Electrical Risks

Based on the use of formal C-A electrical safety procedures, working hot permits and job safety analyses, high or medium consequence levels are extremely unlikely. Thus, the risk is acceptable.

4.5.14. Professional Judgment Issues

The initial screening of Booster Applications Facility hazards was performed using qualitative engineering judgment. The C-A engineering, operating and safety staff has many years of experience with BNL accelerators and experiments. NASA experiments have been conducted using appropriate beams from the AGS to target caves in Building 912. This experience influenced the analyses of [Appendix 9](#).

[Appendix 3](#) describes the bases for conservative maximum hourly routine and faulted beam energy limits which have been used as the bases for the shielding and ALARA analyses. The judgment issues will be verified by fault studies.

4.5.15. Methods Used in Evaluation of Radiological Hazards

Techniques employed in the evaluation of radiological hazards include the use of empirical formula,^{38,39} and the Monte Carlo Programs MCNPX⁴⁰ and CASIM.⁴¹ [A. J. Stevens](#) indicates CASIM has been used satisfactorily at BNL accelerators for many years at energies above 10 GeV, and has been extensively compared to MCNPX at energies above 2 GeV.⁴² CASIM cannot be used directly for low-energy neutron transport. It has also been found to overestimate neutron flux in the very forward

³⁸ K. Tesch and H. Dinter, "Estimation of Radiation Fields at High Energy proton Accelerators," Radiation Protection Dosimetry, Vol. 15 No. 2 pp. 89-107 (1986).

³⁹ C. Distenfeld and R. Colvett, "Skyshine Considerations for Accelerator Shielding Design," Nucl. Sci. Eng. Vol. 26, p. 117 (1966).

⁴⁰ L. S. Waters, Ed., "MCNPX USER'S MANUAL," LANL Report TPO-E83-UG-X-0001, (1999). See also H.G. Hughes, R.E. Prael, R.C. Little, "MCNPX – The LAHET/MCNP Code Merger," X-Division Research Note, 4/22/97. The version number of the code used in this note is 2.1.5.

⁴¹ A. Van Ginneken, "CASIM; Program to Simulate Hadron Cascades in Bulk Matter," Fermilab FN-272 (1975).

⁴² A. J. Stevens, "N-Shield, Description," BNL C-A Dept. ES&F Division Note 157 (2000). <http://server.ags.bnl.gov/lopresti/157.PDF>.

direction.⁴³ MCNPX is probably the most widely used neutron transport Monte Carlo code. Several MCNPX calculations have shown excellent agreement with empirical labyrinth formula.⁴⁴

Past measurements by [Stevens](#) at approximately 90° have been made in BNL soil. They show that Booster Applications Facility calculations are overestimates and should be regarded as upper limits.⁴⁵

⁴³ See above reference. The CASIM estimates of soil activation in the dump region are in fact overestimates. Conversely, CASIM dramatically underestimates neutron flux in the backwards direction, but no such estimates exist in the Booster Applications Facility geometry.

⁴⁴ K. Goebel, G.R. Stevenson, J.T. Routi, and H.G. Vogt, "Evaluating Dose Rates Due to Neutron Leakage Through Access Tunnels of the SPS," CERN LABII-RA/Note/75-10 (1975).

⁴⁵ A.J. Stevens, "Summary of Fault Studies at RHIC." BNL C-A Dept ES&F Note 156 (2000).
<http://server.ags.bnl.gov/lopresti/156.PDF>